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Systematic Review

Training Impulse and Its Impact on Load Management in Collegiate and Professional Soccer Players

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Abstract: Methods: Training impulse (TRIMP) is obtained through wearable technology and plays a direct role on the load management of soccer players. It is important to understand TRIMP to best prepare athletes for competition. A systematic search for articles was conducted using Google Scholar, with papers screened and extracted by five reviewers. The inclusion criteria were: the study was focused on collegiate or professional soccer, the use of training impulse (TRIMP), and the use of wearable technology to measure TRIMP. Of 10,100 papers, 10,090 articles were excluded through the systematic review process. Ten papers were selected for final review and grouped based on (1) training vs. match (N = 8/10), (2) preseason vs. in-season (N = 3/10), and (3) positional comparison (N = 3/10). Wearable technologies mainly track physical metrics (N = 10/10). Higher TRIMP data were noted in starters than reserves throughout the season in matches and slightly lower TRIMP for starters vs. reserves during training. TRIMP data change throughout the season, being higher in preseason phases compared to early-season, mid-season, and late-season phases. These findings help highlight the benefits of TRIMP in managing internal player load in soccer. Future research should focus on utilizing wearable-derived TRIMP and the impact on player performance metrics, and how TRIMP data vary across different positions in soccer.

Keywords: soccer; football; training impulse; TRIMP; internal load; recovery

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1. Introduction

Tracking physical and physiological workloads is an ever-evolving, practical tool used to manage fitness, injury risk, and overall player development in high-performance sports [1,2]. As soccer gains more popularity around the world, so too does the use of technology and its impact on the load management of players [3]. Although coaches and athletes look for ways to amass marginal gains throughout congested seasons, it is still important to account for accumulated load by altering player workloads throughout a season [2]. Identifying key metrics that can display discrepancies between competition and training may be helpful to training and coaching staff to better manage training and workload throughout the season in soccer players [4]. It is essential to understand how both internal and external training loads play a role in load management across different parameters. For example, differences in training stimuli can be expected between players because different tactical roles require different movement patterns and physiological responses [5]. It is essential to possess knowledge of the internal and external training load to ensure optimal training loads and recovery are met.

External load is associated with physical work being carried out in the form of movements, while an internal load is the body's physiological response to biological stressors [1]. External load measures in soccer include peak velocity, acceleration, distance covered, power output, and specific distances covered at varying velocities [1,4,6]. External load is usually measured using GPS technology or accelerometers (e.g., Playertek, Apex, and

Catapult). In contrast, internal load is measured objectively by utilizing heart-rate-derived measurements (HR and training impulse (TRIMP), and subjectively by utilizing session ratings of perceived exhaustion (sRPE). Training impulse, otherwise known as (TRIMP), is calculated using training duration, and resting, maximal, and average heart rate [3]. The different TRIMP methods observed in this systematic review included Bannister's TRIMP, team TRIMP, iTRIMP (individualized TRIMP), Edward's TRIMP, modified TRIMP (Stagno), and Lucia TRIMP [1–5,7–11].

Understanding how internal and external load data are measured is important for monitoring the load management of players throughout the season. This can be performed by comparing preseason to in-season phases, position-specific demands, and training vs. match data. Specific player metrics such as TRIMP can be influenced by position-specific demands, playing time, preseason vs. in-season comparisons, and training data vs. match data. These data are traditionally assessed by comparing internal training load to other measures such as RPE. However, there have been suggestions that the magnitude of these correlations can vary depending on the session training topics [1,10]. In this instance, more significant correlations were observed (r = 0.82) between session RPE and Edwards's training load while measuring activity in a predominately low-intensity aerobic workload. In comparison, female soccer players reported low magnitude associations (r = 0.25) in more neuromuscular types of sessions (i.e., Session Type Resistance) [4]. These findings appear to suggest that the session RPE method might not reflect the underlying HR-inferred physiological stress arising from some of the sessions typically performed by soccer teams.

There is a need to perform a systematic review regarding the use of wearable technology to determine the player load in soccer. Wearable technology (such as Apex, VX-sport, and Catapult) available to soccer players allows coaches, staff, and trainers to tailor drills and training loads with the aim for players to be in optimal condition for competition, allowing athletes to be on the field in critical moments [5,10]. Quantifying the training load can be challenging throughout a season and during training due to the large numbers of athletes and their activity levels throughout these sessions [1]. To combat these challenges, specific wearable technology options available to soccer players can show data on various performance-based metrics, including acceleration, heart rate, foot contacts, and even balanced-based movements [8,12]. The devices, such as the Apex system, allow coaches and the training staff to see when players begin to load and favor one side. Certain systems even calculate proprietary metrics to further characterize the internal and external workload demands incurred by athletes, some of which are summated throughout a session and reflect both the volume and intensity of work (i.e.,), training load by Polar and player load by Catapult. This review aimed to understand the use of wearable technology in soccer to monitor internal heart-rate-derived impulse (TRIMP) while managing the training load and to better understand its impact on varying parameters throughout the season.

2. Methods

A systematic review approach was completed on 21 September 2022. Studies were identified through the library database system Google Scholar at the University of Nevada, Las Vegas. Google Scholar does not allow users to go past 100 pages (1000 articles) of results [11]. Therefore, initial search yielded 10,100 results, and the first 1000 articles were analyzed. Key terms used in this search were the following: soccer OR football AND training impulse OR TRIMP AND internal load AND recovery. Inclusion and exclusion criteria followed the PICO parameters (see Table 1).

A systematic scoping search was carried out across the Google Scholar database, where wearable technology was employed to assess internal load (see Figure 1). Articles were excluded if they focused on sports outside of "Soccer," "football," and "futbol", did not include TRIMP design, and did not measure preseason vs. in-season, position-specific, or training vs. match data. A total of ten articles were selected for full-text analysis.

Table 1. PICO inclusion criteria.

Item	Criteria	Example
P = Population	Collegiate or professional soccer/football players (16+ years)	NCAA Division 1 soccer players
I = Intervention	Utilize internal load of HR-derived impulse (otherwise known as TRIMP)	Edward's TRIMP Bannister TRIMP Lucia TRIMP
C = Comparator	Preseason vs. in-season (season comparison), gameplay performance and training vs. match, training program, gameplay time (positional comparison)	TRIMP data for preseason vs. in-season
O = Outcome	Impact on recovery, either positive or negative, statistically significant, effect size, etc., based on training, gameplay	ANOVA Descriptive statistics reported
S = Study Design	Full-length season, full-length pitch, training vs. match, position comparison, available in English, preseason vs. in-season	Two consecutive fall seasons

These studies were peer-reviewed, full text, English, scholarly journals, and occurred between 2010 and present; we also unchecked "Include Patents" and "Include Citations". Exclusion criteria for these studies were different languages, non-peer-reviewed topics unrelated to soccer or football, articles before 2010, and anything outside the above-stated criteria. The first step in this process was to determine all inclusion criteria by viewing relevant studies by title and highlighting the key terms. If the titles were related to the inclusion criteria, the second step was to read and analyze the abstract of the articles. The third step was to read through all articles collected and then put them into subcategories based on the key terms/topics. Subtopics were separated between training vs. match, a seasonal comparison focused on preseason and in-season data, and a positional comparison. The last step in this systematic process was to complete the data extraction. This information included the author, journal title, year published, subjects, measures, methods, results, and discussion section main topics into an excel spreadsheet highlighting the main points and extracting data such as the type of TRIMP utilized. The articles were then divided into subsections in the order used on the spreadsheet based on all inclusion criteria.

2.1. Revised Search Criteria

We initially utilized criteria with the following PICO parameters to better understand the relationship between TRIMP and performance metrics such as passes completed and shots on goal for collegiate and professional soccer players. The population and intervention were the same as stated above; however, the comparator originally included positional comparison data only, and the original outcome looked to assess performance metrics such as passes completed, challenges won, and shots on target, etc. The study design needed to include full-length seasons and data being reported for at least four weeks, and these parameters yielded one result that matched all the above criteria. The biggest limiting factors were the performance metrics stated above, direct position comparison, and at least three weeks of data collection. We decided to focus the review on TRIMP-reported data, look at three comparison categories, and appropriately group articles. Three categories were chosen: training vs. match, preseason vs. in-season data, and positional comparison. The final positional comparison bucket included the one original remaining article and two articles that grouped starters and reserves. This change in terms led us to our final list of ten articles for this review.

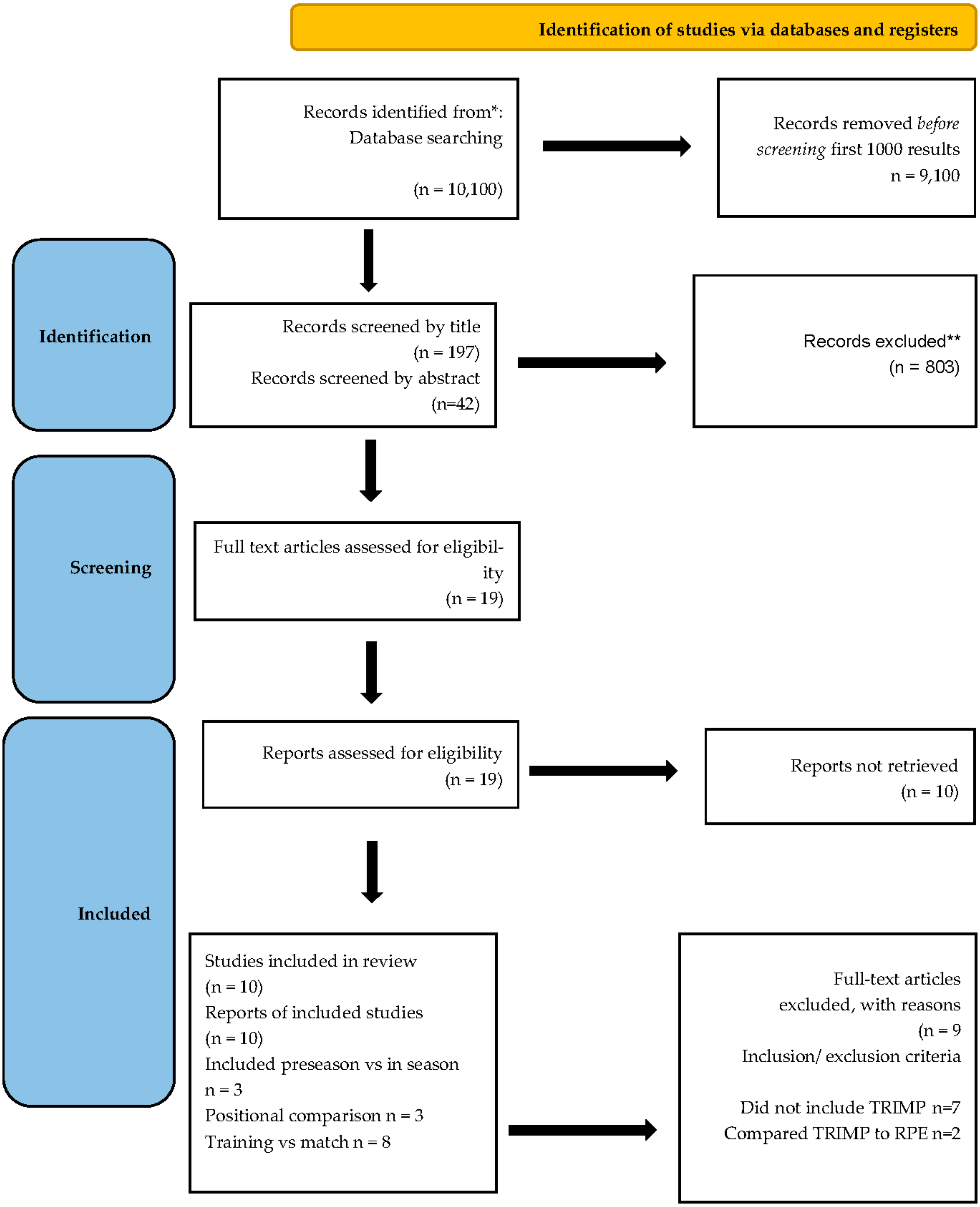

Figure 1. PRISMA Criteria.

2.2. TRIMP methodologies

In order to better understand training impulse as an internal load indicator, commonly used methodologies are explained below.

- Edward's TRIMP is a heart-rate-proposed zone-based method. The time spent in each predetermined percentage zone is multiplied by the coefficient to determine the training load [3,4,11]. This method originally gained popularity as the standard method; however, since the zones are predefined and lack metabolic and performance thresholds, studies have not proven zone five is five times more demanding than zone one in relation to training intensity and adaptations.
- Bannister's TRIMP utilizes the intensity of exercise, utilizing the heart rate reserve and the duration of the exercise [1,8,9,11]. This method is utilized primarily in athletes with long training periods and short competition phases [9,11]. Some limitations of the method for soccer players include the use of the heart rate mean may not reflect heart rate throughout the intermittent exercise. Secondly, there is a universal equation for males and females; this implies that gender is the only factor that makes athletes different.
- Individualized TRIMP is measured by linking an individualized heart rate blood lactate to incremental exercise [7]. This method is not limited by gender because it is individualized to the athlete.
- Lucia TRIMP is a method based on ventilatory thresholds. There are three zones, and each zone is given a coefficient that is multiplied by the time spent in each zone to give a TRIMP score [6]. This method shares some of the same limitations as Edwards since they are not directly linked to performance thresholds; it is difficult to prove that zone three is three times more demanding than zone one [6].
- Finally, modified TRIMP, also known as Stagno's TRIMP, is a modified version of Bannister's TRIMP [5]. This method links the blood lactate threshold to exercise intensity and is linked to each heart rate zone. This method provides some individualized data due to using the individual blood lactate level instead of an equation that reflects hypothetical blood lactate levels.

2.3. Risk of Bias

The Cochrane Risk of Bias Tool 2.0 (ROB 2.0) was used to assess the methodological quality of the individual studies and the risk of bias

3. Results

Ten papers were selected for final review; these were grouped based on the time during the season and included player/position comparison and comparing the data between training and matches. Training vs. match data (N = 8/10), preseason vs. in-season data (N = 3/10), and finally, positional comparison data (N = 3/10) were used. The internal heart-rate-derived training load (TRIMP (N = 10/10) was categorized. We found that wearable technologies, specifically heart-rate-derived equipment, are able to measure training impulse, and with these data, coaches and training staff can make informed decisions on the load management of their players throughout a season.

3.1. Subjects

Participants took part in soccer matches and training sessions and performed movements relating to performance, such as time in specific zones and heart-rate-derived training impulse (TRIMP), monitored by wearable technologies. They utilized devices such as Polar, Catapult, Polar Electro, and other GPS devices. The ten selected studies ranged from the year 2013 to 2022. These studies were collected from the United States, Iran, Spain, Portugal, Brazil, Singapore, and the United Kingdom. The subjects included male and female professional and collegiate soccer players, who were grouped into three categories with some overlaps. These three categories included reported data, firstly consisting of training vs. match (n = 8). TRIMP data were collected and compared in a training setting vs. match data, ranging from two weeks to two consecutive fall seasons [1,3,4,7–12]. Positional comparison data (n = 3) compared starters to reserve players [3,10]. This also included one case study comparing a right back to a midfielder in the first division of a state championship in

Brazil [5]. Finally, seasonal comparison data were assessed (n = 3). These data compared preseason data to in-season data ranging from three weeks to two seasons [5,6,10,11].

3.2. Study Design

These ten studies consisted of nine longitudinal studies and one case study with no parallel or crossover study design. All ten studies were uncontrolled and utilized sample sizes ranging from two participants to 82 [3,5]. All ten studies consisted of observational cohort studies. Data were collected from Polar Team systems [3–7,10], OptimumEye X4 [1]; Catapult Innovations [1], SPI Pro X [9], GPSports, and Canberra [1,3–9]. All but one study conducted statistical analysis. The study that did not perform analysis was Bara-Filo et al. due to it being a case study [5]. The statistical analyses performed included a mixed-effect model with pairwise contrasts, multivariate analysis of variance (MANOVA), descriptive statistics, analysis of variance (ANOVA), and mixed linear modeling [1,3–11]. The final ten articles utilized five unique forms of TRIMP. The five forms included Bannister's (n = 4/10) [1,7,9,11], Edward's (n = 4/10) [3,4,9,11], individualized (n = 1/10) [7], modified (n = 1/10), [5] and Lucia (n = 1/10) [6].

The risk of bias and the methodological quality of the studies included in the present review were assessed using the Cochrane Risk of Bias Assessment Tool (ROB 2.0) (see Figure 2). The assessment tool uses five domains to evaluate the quality of the study and the individual risk of bias ((1) the randomization process, (2) deviations from the intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) selection of the reported result), which produces an overall bias result in the form of "Low risk", "Some concerns"/unclear risk of bias, and "High risk", as seen in the table below. Three studies had at least "Some concerns" for bias due to the measurement of outcomes based on what are believed to be typos and omissions of comparison data.

3.3. Training vs. Match

Akubat et al. conducted a study consisting of nine professional youth soccer players in the UK [7]. The participants were recruited from the same team. This observational six-week study consisted of technical training sessions four to six times per week, with matches being played on Saturdays and two rest days per week (Sunday and Wednesday). The Polar Team system was used for data collection, and the TRIMP measurements reported were Bannister's, team, and individualized. The following TRIMP data were reported: TRIMP = 460 $\pm$ 98, team TRIMP = 1538 $\pm$ 359, and iTRIMP = 1830 $\pm$ 1805; however, these were combined training and match data, so it was not possible to determine how these data compared between the training and match data.

Anderson et al. conducted a study consisting of 26 NCAA division one men's soccer players in the United States [4]. The participants were recruited from the same team. This observational two consecutive fall season study consisted of outdoor training sessions and matches and utilized the Polar Team Pro two to report Edward's TRIMP. The following TRIMP data were reported: absolute TRIMP during training sessions = 214 (75.6), during a match = 449 (116), $p < 0.01$; relative TRIMP (scaled to the duration of the total session) training = 2.81 (0.65), and match = 2.68 (0.66), $p > 0.05$; within subjects. This study found that physical workloads during competition are greater than in training [4].

Askow et al. conducted a study consisting of 22 NCAA division three women's soccer players in the United States [1]. The participants were recruited from the same team. This observational 16-week study collected data during each training session and match utilizing the Catapult system for data collection. TRIMP methods included Bannister's and Edward's TRIMP. The following TRIMP data were reported: Edward's TRIMP match ~350 (150) vs. 150 (125) (high perceived exertion vs. low); practice ~225 (75) vs. 190 (100); Bannister's TRIMP match ~200 (75) vs. 75 (60); practice ~125 (50) vs. 90 (50), and a p-value of $p < 0.001$ for all match vs. practice comparisons was reported. This study found that session RPE is associated with external load measures. They also found that heart-rate-derived training impulse is less sensitive to environmental variations than sRPE, indicating workload measurements may be more indicative of the overall load than with sRPE. Finally, they reported a higher TRIMP measure in matches when compared to training sessions.

Author (Year)	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall
Akubat et al. 2012	+	+	+	?	+	!
Anderson et al. 2021	+	+	+	+	+	+
Askow et a1. 2021	+	+	+	+	+	+
Rabbani et al. 2019	+	+	+	+	+	+
Campos-Vasquez 2015	+	+	+	?	+	!
Costa et al. 2021	+	+	+	+	+	+
Curtis et al. 2021	+	+	+	+	+	+
Bara-Filho et al. 2013	+	+	+	?	+	!
Lee et al. 2019	+	+	+	+	+	+
Jagim et al. 2022	+	+	+	+	+	+

- Low Risk: +
- some concerns: ?
- High Risk: –

Figure 2. Risk of bias assessment [1–10].

Rabbani et al. conducted a study consisting of 11 male professional soccer players in Iran [10]. The participants were recruited from the same team. This observational five-week study consisted of technical, tactical, and conditioning (RT, HIIT, speed, agility, power) training sessions. The SPI Pro X, GPSports, and Polar T34 systems were used for data collection. Bannister's and Edward's TRIMP data were collected. Note* that values are only for practices sessions: Edward's TRIMP = 166.8 (23.2); Bannister's TRIMP = 96.0 (11.0). No practice vs. match data analysis was performed, and TRIMP was only obtained during practice sessions. This study reported that heart-rate-based metrics can be beneficial in monitoring intermittent running in professional soccer players.

Campos-Vasquez et al. conducted a study consisting of nine professional second division men's soccer players in Spain [5]. The participants were selected in a convenience sample. This observational one-season (10-month) study recorded TRIMP for all practices and training sessions, including drills, ball possession games, and tactical training pre-match activation. The Polar Team two systems were used for data collection. TRIMP methodology included Edward's and Stagno's TRIMP. The following TRIMP data were reported: absolute TRIMP training = 214 (75.6), match = 449 (116), $p < 0.01$; relative TRIMP (scaled to the duration of the total session) training = 2.81 (0.65), match = 2.68 (0.66), $p > 0.05$; within subjects. These statistics show that TRIMP was higher during matches than during training when using absolute measures but not when TRIMP was scaled to the duration of the total session; this was reported as relative TRIMP. This study found significant relationships between Edward's TRIMP and sRPE, as well as between Stagno TRIMP and sRPE for drills and small-sided games, and technical and tactical training (r = 0.73–0.87). Correlations between Stagno and Edward's TRIMP were 0.92–0.98 for each exercise. However, it is important to be cautious when using RPE and heart-rate-derived measures of load interchangeably [5].

Costa et al. studied 34 female soccer players with 5+ years of experience in Portugal [8]. The participants were selected in a convenience sample. The observational cohort consisted of a two-week study where TRIMP data were recorded for all practices and matches. This study utilized the Firstbeat heart rate monitor and reported Bannister's Trimp data. Average TRIMP practice and match data were reported as follows: practice TRIMP = 186.33, match TRIMP = 250; TRIMP --> sleep duration: $r = -0.25$ ($p < 0.001$ TRIMP --> sleep efficiency: $r = -0.2$ ($p = 0.004$) This study found that late-night training sessions likely contributed to the inverse relationship between TRIMP and sleep factors. This can be affected by match schedules and overall workload; these variables can impact sleep duration. This study reported a higher match TRIMP than practice TRIMP [9].

Curtis et al. conducted a study of 82 men's NCAA division one soccer players in the United States [3]. The participants were selected in a convenience sample. The observational two-year (two 14-week seasons) study recorded all TRIMP data for practices and matches throughout the two seasons. This study utilized the Polar Team Pro heart rate monitor and GPS. Edward's TRIMP was the selected TRIMP methodology for this study. This study viewed the difference between starters and reserves, and the TRIMP data were reported as follows: starters (S) vs. reserves (R) TRIMP mean difference (MD) for season = 2210 arbitrary units (a.u.) (starters higher); S vs. R TRIMP MD for practice = 1662 a.u. (starters lower). They determined it was very likely to see differences between starters and reserves, ES = 0.63 ± 0.9, during the season (starters higher). This study reported that reserve players showed higher TRIMP data during training sessions when compared to starters. They determined it was very likely that there were differences between S vs. R for practices, with an effect size = -0.79 ± 0.55 (starters lower) This can be explained because of an imbalance in the overall workloads between players and their positions [3]. It is important to manage workloads for different players throughout the season; individualized monitoring through these wearable devices makes this task easier for coaches and training staff. This study was included in this section because it included both training and match data; however, this study did not report the difference between training and match data.

Jagim et al. conducted a study of 22 collegiate women's soccer players in the United States [9]. Participants were selected in a convenience sample. The observational one-season study recorded TRIMP data for all practices and matches throughout the season. The Polar Team Pro heart rate monitor and GPS were used to collect data. This study did not specifically define TRIMP, and it is unclear if "training load" is heart-rate-derived TRIMP. The authors have been contacted for clarification. This study compared starters and reserve training load, and the training load data were reported as follows: training load

(TRIMP) total season (match + practice) for starters: 9431 ± 1471 vs. reserves: 6310 ± 2263; training Load (TRIMP) matches for starters: 5515 ± 753 vs. reserves: 2392 ± 1217; training load (TRIMP) practice for starters: 3916 ± 885 vs. reserves: 3918 ± 1358. This study found that starters covered more distance throughout the season, which resulted in almost double the training load when compared to the reserves [10]. This was reported as the training load was significantly higher in starters compared to reserves for the full season ($p = 0.002$; d = 1.54 [0.56, 2.53]) and matches ($p < 0.001$; d = 2.90 [1.68, 4.12]). These data did not differ between starters and reserves during practice sessions throughout the season ($p = 0.998$; d = 0.00).

These eight studies found that TRIMP-reported data were higher in matches than in training sessions. While many of these studies supported this conclusion (n = 6/8), some factors were responsible for TRIMP-reported data being reported inversely when comparing training vs. match data. This was seen in the study by Curtis et al. that reported lower TRIMP data for starters in practice compared to reserve players [3]. This is due to reserve players demonstrating increased load during training because they endure less load throughout the season in matches where they are playing less [3]. Overall, these eight studies found TRIMP is higher in matches than in training due to the intermittent nature and increased workloads of the match being greater than the controlled environment of training sessions (see Table 2) [1,3,4,7,9–12].

3.4. Seasonal Comparison

The two additional studies were classified into the seasonal comparison category. This category assessed TRIMP-reported data in preseason vs. in-season competition phases throughout the season; these two studies are highlighted below.

Bara-Filho et al. conducted a study of two first division state championship Brazilian professional soccer players [2]. Participants were selected from the same team in this sample. The observational case study occurred over a three-week period in the season. TRIMP data for all practices and matches throughout this period were recorded. The Polar RS 800 system was used to collect data. Modified (Stagno) TRIMP was used in this study, and the data were reported as follows [5]. Athlete 1 (midfielder): 1280, 814, and 930 for weeks 1, 2, and 3, respectively. For athlete 2 (right back): we believe there is a typo reported in the data since 110 is a large outlier compared to the other data: 110 (potential typo, perhaps 1110), 930, and 932 for weeks 1, 2, and 3, respectively. These data are not easy to summarize due to the outlier; we have reached out to the authors for clarification.

Lee et al. conducted a study of 29 assumed male professional soccer players (it was not explicitly stated that males were used, but we based our conclusion on the reported height and body mass of participants) in Singapore [6]. This observational study lasted two seasons, and participants were recruited from the same team. This study used the SPI Pro X, GPSports and Polar T34 systems to measure TRIMP-reported data. The Lucia TRIMP was used in this study, and data were provided for mid-season (MS), late in the season (LS), preseason (PS), and early in the season (ES) phases. MS vs. LS: −14.2* * represents $p < 0.05$, −0.48 effect size (small effect size); MS vs. ES: −2.7, −0.09 ES (trivial); LS vs. ES: 11.5*, 0.37 ES (small); PS vs. ES: −1.3, −0.04 effect size (trivial); PS vs. MS: 1.4, −0.05 (trivial); and PS vs. LS: −12.8*, −0.043 effect size (small). This study found significant effects based on training load throughout different points in the season. Training performance was also influenced by the phase of the season [6]. TRIMP-reported data were highest in the preseason phase when compared to the in-season phases of the season; this is due to the primary focus on building players up for the season [6]. Early-season data were lower than preseason since the load is dialed back early in the season. Mid-season data reported a lower TRIMP load since low-intensity distance is prioritized since recovery from matches is most important. Late-season showed the lowest internal- and external-load-reported data due to the overall buildup of load throughout the season and increased recovery time needed for upcoming matches.

Table 2. Training vs. match TRIMP comparison table.

Author	Year	Cross Sectional or Longitudinal	Sample Demographics	Number of Training Sessions and Matches	TRIMP Method	Analysis Performed	Results Training vs. Match
Akubat et al. [7]	2012	Longitudinal	Mean age 17 + 1 years; stature 1.81 + 0.05 m; body mass 72.9 + 6.7 kg	N/A	Bannister's TRIMP, Team TRIMP, iTRIMP (individual-ized TRIMP)	No match vs practice analysis performed	Values were combined
Anderson et al. [4]	2021	Longitudinal	Age: 20 (2) y, body mass: 75.8 (5.9) kg, and height: 178 (6.8) cm	87 training sessions and 34 matches	Edward's	Mixed-effects model with pairwise contrasts	TRIMP in matches vs. training
Askow et al. [1]	2021	Longitudinal	Age: 20.3 (1.5) y, body mass: 65.1 (7.2) kg; height: 168.4 (7.9) cm	47 practices 22 matches	Bannister's Edward's	MANOVA	TRIMP in matches vs. training
Rabbani et al. [10]	2019	Longitudinal	Age: 27.2 (4.5), body mass: 72.7 (6.6) kg, height: 180.4 (9) cm	21 training sessions, 4 matches	Bannister's Edward's	No match vs practice analysis performed	TRIMP only obtained in matches
Campos-Vasquez et al. [5]	2015	Longitudinal	26.7 ± 4.5 years, 176.5 ± 6.8 cm, 74.5 ± 5.7 kg, 10.1 ± 0.8% BF, 4.5 ± 4.1 years professional play. Mens soccer.	288 individual training sessions (does not specify if that is team "sessions" or individual data,)	Edward's Stagno	correlations, magnitude-based inferences	Absolute TRIMP in matches vs. training Relative TRIMP in training vs matches when TRIMP was scaled to duration of total session
Costa et al. [8]	2021	Longitudinal	Female soccer players, 20.06 ± 2.3 years, 1.6 ± 0.1 m, 22.1 ± 2.3 kg, 11 attackers, 10 midfielders, 7 fullbacks, 6 central defenders.	6 practices 2 matches	Bannister's	Descriptive and correlations for TRIMP	TRIMP in matches vs. training
Curtis et al. [3]	2021	Longitudinal	20 ± 2 years, 77.4 ± 5.1 kg, 179.9 ± 6.5 cm, 9.9 ± 2.4% BF, 53.8 ± 4.1 mL/kg/min, male soccer players	20 ± 2 games and 48 ± 6 practices over 14 ± 1 week season	Edwards	Multilevel mixed models to test differences between starters and reserves. Magnitude based inferences.	Did not report specific training vs. match data However, TRIMP was In reserves vs. starters
Jagim et al. [9]	2022	Longitudinal	female soccer players, 1.67 ± 0.05 m, 65.42 ± 6.33 kg, 48.99 ± 3.81 FFM (kg), 25.22 ± 4.78% BF	47 practices, 22 matches (1444 unique player sessions)	Not Specified	RM ANOVA with Bonferroni adjustments for multiple comparisons, Cohen's d ES	TRIMP in starters in matches vs. reserve players TRIMP in reserves in training vs. starters

The findings of Rabbani et al., which have been discussed above, were included in this section due to their inclusion of practice and match TRIMP; however, no analysis was performed [10]. This study did represent that TRIMP was higher in the early to midpoints of the four collected matches before tapering off. This study also showed higher TRIMP before those matches than after, which is in line with initial findings of TRIMP being higher prior to matches than after the season.

These three studies highlight that training loads are associated with performance while being limited in their data (see Table 3). To maximize performance for athletes, it is important to manage recovery and overall training load throughout a season [5,6,11]. For example, in mid-season phases, low-intensity distance is prioritized, which lowers training intensity while focusing on recovery. Coaches do this due to there being more matches and an increased workload throughout the season. While preseason sees increased loads because players are preparing for the season, in the late-season phase, players' internal and external loads are at their lowest, where coaches can prioritize tactical training such as walkthroughs and analysis of performance [6].

Table 3. Preseason vs. in-season TRIMP comparison table.

Author	Year	Cross Sectional or Longitudinal	Sample Demographics	Number of Training Sessions and Matches	TRIMP Method	Analysis Performed	Results Seasonal Comparison
Bara-Filho et al. [2]	2013	Longitudinal Case study	Age: 19 and 26 y, Body fat: 10.1 and 10.6%, VO2max: 60.8 and 62.3 (mL/kg/min)	3-week period with 3 matches (friendlies)	Modified TRIMP (Stagno)	Case study—no analysis performed	This data is not easy to summarize due to the outlier we have reached out to the authors for clarification.
Lee et al. [6]	2019	Longitudinal	Age: 26.2 (3.8), body mass: 68.5 (8.6) kg, height: 173.6 (5.6) cm, body fat: 15.1 (4.5)%	42 training sessions	Lucia TRIMP	Mixed linear modeling	Pre-season TRIMP vs. early season Early season vs. midseason Midseason vs. late-season Overall pre-season TRIMP was higher and TRIMP decreased over the season since recovery is prioritized
Rabbani et al. [10]	2019	Longitudinal	Age: 27.2 (4.5), body mass: 72.7 (6.6) kg, height: 180.4 (9) cm	21 training sessions, 4 matches	Bannister's TRIMP, Edward's TRMP	No seasonal analysis performed	TRIMP prior to matches than after the season where TRIMP is lower

3.5. Positional

The Bara-Filho et al. study was included in this section to directly compare two players in the same team playing different positions (right back and midfielder) [2]. This study showed unique TRIMP-reported data; however, we have reached out to the authors for clarification since we believe there is an outlier in the final reported data.

The Curtis et al. study reported higher load measurements across all reported metrics [3]. Specifically, TRIMP in starters was higher when compared to reserve players over the season and in matches. Starters accumulated substantially more total distance (mean difference (MD) 5.82 km, effect size 51.23), training impulse (TRIMP) (MD 52,210 au, effect size 50.63), and total accelerations (MD 56.324 n, effect size 50.66) over the season. Reserves accumulated substantially more total distance (MD 5.20 km, effect size 50.43) and TRIMP (MD 51,683 arbitrary units (au), effect size 50.79) during training [3]. Lower TRIMP can be attributed to starters focusing more on recovery from matches during training since they are playing more throughout the season.

Jagim et al. found that starters covered more distance throughout the season, which resulted in almost double the training load when compared to the reserves [9]. Training load (TRIMP) for the total season (match + practice), starters: 9431 $\pm$ 1471 vs. reserves: 6310 $\pm$ 2263.

These three studies assessed data by specific position and by the classification of starters vs. reserves (see Table 4). The data showed that, generally, starters experience increased load throughout the season compared to reserve players [5,10]. This is generally the case due to starters playing more minutes, where the training load is higher in matches compared to training [1,3,4,7,9–12]. Some factors show an inverse relationship between starters and reserves, as discussed above. Regarding position-specific demands, there are unique needs for each position. For example, goalkeepers were excluded from all of these training-load-reported studies due to their position-specific demands being very different from outfield players. Unfortunately, the one study that focused on two different player positions we believe has a typo in their reported data. Hence, it is difficult to make a conclusion on how the training load impacts specific positions over a season.

Table 4. Positional TRIMP comparison table.

Author	Year	Cross Sectional or Longitudinal	Sample Demographics	Number of Training Sessions and Matches	TRIMP Method	Analysis Performed	Results Positional Comparison
Bara-Filho et al. [2]	2013	Longitudinal Case study	Age: 19 and 26 y, Body fat: 10.1 and 10.6%, VO2max: 60.8 and 62.3 (mL/kg/min)	3-week period with 3 matches (friendlies)	Modified TRIMP (Stagno)	Case study—no analysis performed	It is not easy to summarize this study due to the outlier; we have reached out to the authors for clarification.
Curtis et al. [3]	2021	Longitudinal	20 ± 2 years, 77.4 ± 5.1 kg, 179.9 ± 6.5 cm, 9.9 ± 2.4% BF, 53.8 ± 4.1 ml/kg/min, male soccer players	20 ± 2 games and 48 ± 6 practices over 14 ± 1 week season	Edwards	Multilevel mixed models to test differences between starters and reserves. Magnitude based inferences.	Did not report specific training vs. match data However, TRIMP was in reserves vs. starters
Jagim et al. [9]	2022	Longitudinal	female soccer players, 1.67 ± 0.05 m, 65.42 ± 6.33 kg, 48.99 ± 3.81 FFM (kg), 25.22 ± 4.78% BF	47 practices, 22 matches (1444 unique player sessions)	Not Specified	RM ANOVA with Bonferroni adjustments for multiple comparisons, Cohen's d ES	TRIMP in starters in matches vs. reserve players TRIMP in reserves in training vs. starters

4. Discussion

This review aimed to quantify accumulated internal training load (TRIMP) by reviewing training vs. match, preseason vs. in-season, and position-specific workloads in collegiate and professional soccer players. This review focused on selecting the novel training impulse (TRIMP) variable instead of quantifying load to sRPE, which has become more common in wearable-technology-related studies. The reasoning for choosing TRIMP instead of sRPE for soccer-specific activity was supported by Akubat et al. In this instance, more significant correlations were observed (r = 0.82) between session RPE and Edwards's training load while measuring activity in a predominately low-intensity aerobic workload. In comparison, female soccer players reported low magnitude associations (r = 0.25) in more neuromuscular types of sessions (i.e., Session Type Resistance) [4]. These findings appear to suggest that the session RPE method might not reflect the underlying HR-inferred physiological stress arising from some of the sessions typically performed by soccer teams. Wearable technology usage is still in an exploratory phase, but there is potential for this technology to positively influence coaching practice and athletes' training load to monitor recovery, and we believe this review can help to explore these needs.

Brain–computer interfaces (BCIs) are an emerging technology that allows communication between the brain and an external device [13]. While BCIs are in the early stages of development, this technology has the potential to be impactful in movement activities including sports [14]. The current systematic review has highlighted the current state of player load management in soccer. While such research is in its infancy [15], it is tempting to speculate that BCIs could be used to manage TRIMP in soccer players by monitoring brain activity during training sessions and games, determining when mental fatigue and stress are experienced [16]. Data supplied by BCIs in real time could monitor brain activity to provide feedback on a player's attention and focus, to help optimize a player's mental state, and to reduce the risk of mental fatigue [17]. Finally, BCIs could be used to individualize and customize programs for soccer players who may have experienced a plateau in training [18].

Another technology that could impact how TRIMP is managed in soccer is virtual reality (VR). The use of VR technology is an emerging topic in tandem with soccer performance [19,20]. VR creates a simulated environment and could be utilized to manage TRIMP by providing an immersive and interactive training environment by simulating game situations [21]. This could allow players to improve skills without the physical strain of gameplay. VR could also be used to simulate different playing surfaces and weather conditions, allowing the visualization of various conditions while potentially reducing the risk of injury [22]. Finally, it is possible that VR could be utilized in soccer to improve players' self-confidence as has been used in software development courses on programming and self-efficacy [17,23].

Immersive VR has the potential to support vision screening in soccer by providing realistic interactive environments for athletes. Potential applications of VR for screening in soccer include (1) visual acuity testing: headsets could be used to display visual acuity charts, presented at different distances and angles to simulate soccer-specific scenarios, (2) depth perception testing: because depth perception is critical in soccer, VR could be used to present a series of virtual objects at different distances and angles requiring players to identify an appropriate decision for any given on-field situation, (3) eye tracking: eye-tracking technology could assess the visual processing speed and accuracy of different player positions, and (4) reaction time testing: VR could present soccer-specific visual stimuli and the reaction time response of players could be measured. The integration of these approaches could improve players' self-confidence or self-efficacy, and this focus of investigation should be conducted in the future.

We anticipate one future issue will be how to manage the large volumes of data produced by wearable technology, particularly as multiple devices are employed that are more sophisticated in returning information related to player load. Sport scientists will likely need to become familiar with query methods, such as Language-Integrated Query (LINQ), that are capable of integrating information from different types of data sources. We are unaware of the literature utilizing the combination of LINQ and any area within sport science; thus, this is also an area rich for investigating.

Limitations of studies: Some studies in this review presented limitations. These limitations varied from combining TRIMP match and training data [7] to our belief that there was a typo in some of the reported data, which made it difficult to determine results for position-specific TRIMP demands [2]. While these studies presented limitations, they were still successful in helping determine how TRIMP data are measured in collegiate and professional soccer players; the authors of these studies have been reached out to for clarification.

Limitation of search criteria: There were a few limitations regarding the search criteria throughout this systematic review. As discussed previously, this review utilized the Google Scholar database, and one limitation of only using this database is that it does not allow users to go past 100 pages (1000) of results [11]. Another limitation regarding the search criteria was that the original criteria focusing on position-specific TRIMP data and its direct relationship to the performance-reported metrics (i.e., dribbles, shots taken, passes completed) yielded one result. We then amended the criteria focusing on the three subcategories of preseason vs. in-season, position-specific, which included starters and reserve classifications, and training vs. match data. This reclassification of search terms yielded the final ten articles for the review.

5. Conclusions

The studies selected for this systematic review showed meaningful workload differences between starters and reserves [3,10]. The main finding in positional differences showed that starters accumulated substantially more total distance over the season. Reserves accumulated substantially more total distance and TRIMP during training [3]. This can be attributed to starters focusing more on recovery from matches during training since they are playing more throughout the season. This category was limited due to the low volume of articles focusing on position-specific demands; however, this provides a great direction for expanding the industry's understanding of the load management and position-specific demands of high-level soccer players. Studies focusing on training vs. match reported data showed TRIMP measurements being higher in matches than in training. This was due to the intermittent nature of matches and the increased workloads of matches compared to training [1,3,4,7,9–12]. Preseason vs. in-season TRIMP data showed that load changes throughout a season, and it is important to be able to manage this to improve performance while managing recovery [9]. Understanding and anticipating these challenges can help coaches and training staff implement proper progressions and recovery for their players and teams throughout the season. These main findings were supported by

Lee et al., who showed differences in TRIMP and training load when comparing preseason, early-season, mid-season, and late-season phases [6]. In conclusion, these studies were able to show the novel and relevant use of TRIMP as a measurable variable in soccer players. This review found higher TRIMP data in starters than reserves throughout the season in matches while showing slightly lower TRIMP for starters vs. reserves in training. This review found that TRIMP data changed throughout the season; it showed that TRIMP data were higher in preseason phases compared to early-season, mid-season, and late-season phases. This review will help understand the benefits of TRIMP data in managing soccer players' internal player load. More research needs to be conducted to understand how TRIMP can specifically impact player performance metrics and how TRIMP data vary across different positions in soccer.

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