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# A systematic review of velocity and accelerometer thresholds in soccer

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## Abstract

**Background:** Velocity and acceleration have been highlighted as the most critical variables in soccer. However, there is a consensus gap in defining different levels of effort.

**Aim:** The purpose of this systematic review is to identify if it is a consensus in those articles that proposed a threshold to establish (i) movement intensity at different velocities using tracking systems and (ii) accelerations using inertial measurement units, classifying the justification methods.

**Method:** A systematic review of Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science databases was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

**Results:** Of the 1983 studies initially identified, 39 were thoroughly reviewed, and their outcome measures were extracted and analyzed.

**Conclusion:** The 40-m maximal linear sprint and physical fitness tests are the most commonly used methods to generate speed and acceleration thresholds in soccer. However, there is substantial heterogeneity in locomotor test procedures and workload zones established from these performance data. Studies diverged when considering the use of individualized thresholds. The low sampling rate ($\leq$ 10 Hz) in the publications calculating acceleration and deceleration demands should also be interpreted cautiously. The present study collected evidence to help professionals process and interpret external load data. More interventional work is needed to confirm the value of fitness-based individualizations.

**Keywords**

Global positioning system, inertial measurement unit, performance analysis, speed, sprint, team sport

## Introduction

The soccer game is characterized by its intermittent regimen in periods of low-to-moderate intensity interspaced with high-intensity efforts.[1] Since the intermittent efforts, monitoring the players' external load (or physical demands) is not as simple as assessing the total distance covered.[2] In fact, as an intermittent running-based activity, the monitoring process of soccer depends on the intensity of running and the amount of time spent at different velocity thresholds.[3] This monitoring process helps coaches and sports scientists to identify the physical demands imposed by the match and to adjust the

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training load to the individual or collective needs of the players.[4] A proper individualization of the training stimulus will consider the specific demands of each player (mainly considering playing position), and specific information about physical demands in different intensity zones is required.[5]

Usually, external load demands imposed by the match are assessed by microelectromechanical instruments, in which the global navigation satellite system, local position system, and/or inertial sensor units are the most popular and used.[6] These instruments control players' displacement in a specific timeframe, thus allowing them to measure not only the distances covered but also the velocity in which these distances are covered or the intensity of accelerations and decelerations during the movements performed.[7] Since the great amount of data generated, the definition of intensity zones becomes essential since coaches should consider the amount of low, moderate, or high demands for each player, aiming to control not only the prevalent intensities but also the determinant ones.[8]

However, low-intensity running is prevalent in match scenarios. The most determinant running activities are related to the most intensity zones, namely considering the associations with a specific player's performance or using this information to control the injury risk.[9] Information about peak velocity, high-speed running, or sprinting running has been used to manage training stimulus, implement preventive training programs, or identify mediators or moderators of injury.[9,10] Therefore, establishing thresholds for running or acceleration/deceleration intensities are determinants.

The process of definition of thresholds is not easy and far from being ideal. Velocity thresholds can have a basis on the energetic systems and points of the threshold.[11,12] However, this would lead to individual velocity thresholds for each player based on capacity.[13] Despite such an approach, this is not easy to implement, and for that reason, standard velocity thresholds (for all players) are the most common practice in external load monitoring.[14] Despite this standardization for all players, the velocity thresholds vary from company to company of devices or study. It also increases the complexity of understanding variations in these demands between players and contexts.

Due to the wide range of running and acceleration/deceleration thresholds used in the literature, it is essential to summarize the evidence and provide recommendations for standardization in the future. It will improve the capacity to compare results across different scenarios and generalize evidence. Although the importance of such summarization, as far as we know, no systematic review has been conducted so far. Therefore, the purpose of this systematic review is to identify if it is a consensus in those articles that purposed a threshold to establish (i) movement intensity at different velocities using tracking systems and (ii) accelerations using inertial measurement units, classifying the justification methods.

## Method

The systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[15] and the methodology to conduct a systematic review of systematic reviews.[16]

### Design

The protocol was not registered prior to the project's initiation and did not require Institutional Review Board approval. The authors performed a systematic search of five databases (i.e. PubMed, Web of Sciences, Cochrane Plus, Proquest, and Scopus) to identify articles published before 4:00 p.m. on 5 October 2020. In all databases, the search was limited to reviews. The authors were not blinded to journal names or manuscript authors. The PICO[15] design was used to provide an explicit statement of the question. Three main groups were created: (1) *sport*: soccer, football; (2) technology-related words: GPS, "global positioning system*," LPS, "Local Positioning Systems," video, camera; (3) variables-related words: "physical performance," "running performance," "match running performance," "movement patterns," "time–motion analysis," "distances covered," "activity profile," "physical profile," "work rate," "match analysis," "match performance," "high intensity," acceleration, deceleration, thresholds, "training load," "acceleration profile," "acceleration zones," "acceleration thresholds," "velocity profile," "velocity thresholds," "velocity zones," "speed zones," "speed thresholds," and "speed profile." The keywords were connected with AND to combine the three groups and using OR to link the words of each group.

*Screening strategy and study selection.* When the referred authors had completed the search (FDS, MRG), they compared their results to ensure that the same number of articles were found. Then, one of the authors downloaded the primary data from the articles (title, authors, date, and database) to an Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, the USA) and removed the duplicate records. Subsequently, the same authors screened the remaining records to verify the inclusion-exclusion criteria (Table 1).

### Data analysis

All studies were summarized and then divided into groups depending on the classification type (i.e. velocity or acceleration). The values are presented in Tables 2 and 3, extracting the following relevant information: EPTS used for data

**Table 1.** Inclusion/exclusion criteria.

| No criteria | Inclusion criteria | Exclusion criteria |
|---|---|---|
| 1 | Studies developed in soccer | Studies conducted in other sports |
| 2 | Studies that identified external training load (velocity or accelerations). | Studies that extracted external TL (not velocity or accelerations) and internal TL. Also, studies not aimed to extract TL. |
| 3 | Studies that provide velocity and acceleration threshold using EPTS or IMU. | Studies that assess other technologies. |
| 4 | Only original and full-text studies written in English | Written in the other language than English. Other article types than original (e.g. reviews, letters to editors, trial registrations, proposals for protocols, editorials, book chapters, and conference abstracts). |
| 5 | Justification of the threshold through a test, competition data, or other analysis techniques | Studies that did not justify the threshold used |

EPTS: electronic performance and tracking systems; IMU: inertial measurement unit; TL: training load.

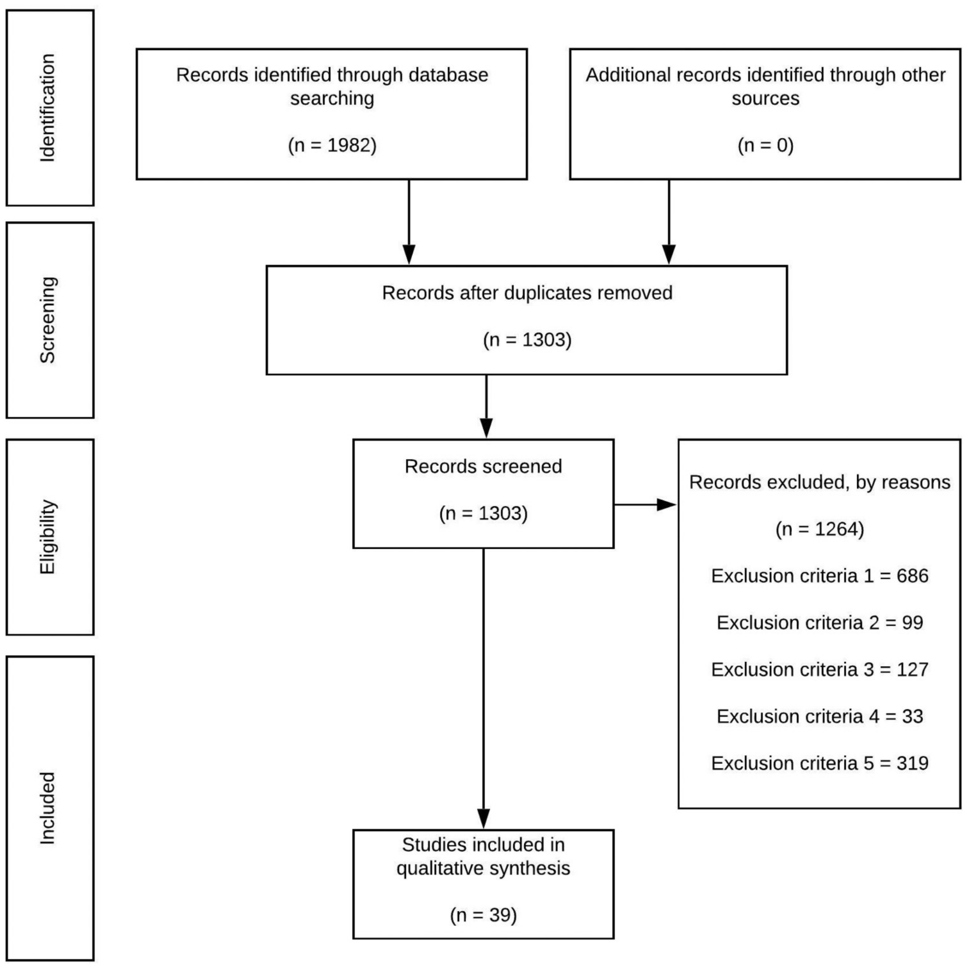


**Figure 1.** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

registration, the manufacturer who belongs to the used EPTS, branch, software in which efforts classification was made, sample, sex, level, task, and thresholds in speed categories. Additionally, these studies were classified depending on the methods used to justify thresholds (e.g. test, maximum speed during training).

## Methodological assessment

The quality of the studies was not assessed because the study's aim was observational; therefore, absolute values from articles were not considered. Therefore, as no quantitative results were included, no quality survey was utilized as evaluation scale. All 39 articles outlined in Table 1 were assessed for suitability and evaluated by authors prior to inclusion. All studies had to meet all items on the *criteria* list to be included in the analysis.

## Results

### Identification and selection of studies

A total of 1982 (i.e. PubMed: 1228; WoK: 754) original articles were initially retrieved from the mentioned databases, of which 679 were duplicates. Thus, a total of 1303 original articles were found. The titles, abstracts, and full texts of these works were checked, excluding 686, 99, 518, 127, 33, and 319 by exclusion criteria number 1, 2, 3, 4, and 5, respectively. Thus, 39 articles met all the inclusion criteria and were finally included in the qualitative synthesis (Figure 1).

### Study characteristics

## Discussion

The main goal of the current work was to systematically review the scientific knowledge contained in peer-reviewed research articles that proposed threshold(s) used in establishing soccer players' movement intensity and analyze if it is a consensus to establish intensity levels in speed and acceleration thresholds. Thirty-nine published papers were considered here addressing velocity and/or acceleration/deceleration bands, respectively, using tracking systems and inertial measurement. Based on these, our main collated findings were: (1) for either velocity zones or acceleration demands, the preferred method to define intensity among studies was based on outcomes from the 40 m sprint test, which was used in more than one-third of all literature covered in the searches; (2) the most frequent data collection systems employed to obtain external load measures were GPSs adjusted at a sampling frequency of 10 Hz (~72%); these were also often used in creating the thresholds (~41%); (3) nearly half of evidence is derived from youth male samples and during competitive matches; (4) there was a predominant choice toward depicting movements solely in the meter unit (~60%), and it is evident that the specific type of displacement recorded is unspecified in all excepting one work. Finally, and of most importance to the current aim (5), it was impossible to identify a standardization in speed categories linked with distinct levels of movement given the wide discrepancies found across literature formulating individualized thresholds.

An essential finding of this review study was that the 40 m sprint test is seemingly the most frequent procedure in establishing individualized speed thresholds in soccer. Recommendations indicated that a 40 m path might be sufficient for players to reach their peak speed, being faster than in competitive matches and thereby possibly representing an adequate method of depicting players' external load.[54] Nevertheless, none of the studies considered the 40 m sprint test either when evaluating players' velocity[17–27] or accelerations/decelerations,[11,12,52] there was a mention regarding its measurement properties (e.g. validity and reliability) for the specific population assessed while only three[11,12,23] provided references which commented or directly determined a given of these aspects ($r = 0.95$–$0.97$; ICC = 0.94–0.99; TEE = 1.67–1.95%).[37,55] The transference of a locomotor testing outcome to match-play running performance is also critical when selecting appropriate testing tools. The so-called construct—or ecological—the validity of the 40 m sprint test lacks consensus [see for a review:][56] as reports are confirming its associations with match running performance[57] whilst no meaningful[37] or only position-dependent results were elsewhere observed.[58] One existing potential solution is the adoption of the maximal sprinting speed (MSS)[59] or a clustering technique using players' velocity samples,[60] both obtained in their matches as input parameters to obtain thresholds. Nevertheless, only a few studies included here considered in-game MSS,[47–49] and the clustering method was challenged.[61] Thus, despite gaining popularity to help individualize soccer demands, doubts may persist on the practical value of the 40 m on-field sprinting test

It is important to note that the individualization of thresholds may arguably benefit soccer practitioners. Examples include an a priori more accurate representation of the player's demands experience in practice or match-play when using individualized thresholds. Enhanced ability to manage individuals' workloads will theoretically allow for the design of more effective recovery schedules and periodization training.[19,30,31,59] Also, the use of customized thresholds helps reduce high-speed running variability within and between matches and from an individual or position-specific point of view.[62] On the other hand, some studies provided evidence that it can represent no additional value to understanding soccer external loads. The clearest example falls in the case of determining dose–response to daily training routines. MSS in a 40 m test routine showed poor correlations with heart rate, ratings of perceived exertion,[26] and wellness.[27]

Furthermore, MSS is not necessarily higher in 40 m testing than in match-play outputs.[63] Most important, training-induced adaptations in running performance encountered during actual match-play are not always matched with those changes verified in 40 m sprint

**Table 2.** Classification of speed categories.

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | Type of displacement | Task | Speed categories | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
| *Maximum speed in 40 m* | | | | | | | | | | | | | | | | | |
| Buchheit et al.[17] | Timing gates at 10, 20, 30, and 40 meters | GPS 1 Hz | GPSports | SPI Elite | Unspecified | 99 | Male | Youth U13 at U18 | Number of repeated sprints and durations | Unspecified | 42 competitive matches | | | | > 61% Vmax | | |
| Scantlebury et al.[18] | Fastest 10 m split of the 40 m sprint with GPS 10 Hz | GPS 10 Hz | Catapult | Optimeye S5 | Sprint 5.17 | 8 | Male | Youth U17 | Meters | Unspecified | 14-week in-season training | | | < 61% Vmax | > 61% Vmax | | |
| Hunter et al.[19] | Timing gates at 10, 20, 30, and 40 m | GPS 5 Hz | Catapult | MinimaxX | Unspecified | 12 | Male | Youth U18 | Meters and percentage of distance covered | Unspecified | 22 competitive matches | | | < 49% Vmax | 50–59% Vmax | 60–79% Vmax | 80–100% Vmax |
| Tomazoli et al.[20] | Timing gates at 10 m, front foot 0.5 m behind the first timing gate | GPS 10 Hz | Catapult | Optimeye S5 | Sprint 5.0.6 | 12 | Male | Youth U19 | Meters | Unspecified | 10 competitive matches | | | < 49% Vmax | 50–59% Vmax | 60–79% Vmax | 80–100% Vmax |
| Sparks et al.[21] | Photocells placed at the start, 30 and 40 m | GPS 10 Hz | Catapult | MinimaxX V4.0 | Logan Plus V4.7.1 | 13 | Male | University football | Absolute and relative time | Unspecified | Five competitive matches | | < 34% Vmax | 34–61% Vmax | >61% Vmax | | |
| Meylan et al.[22] | Dual-beam timing light system placed at 0, 10, and 40 m with the preferred leg forward 0.3 m behind the starting line and GPS 10 Hz | GPS 10 Hz | Catapult | Minimax S4 | Sprint 5.1.0.1 | 20 | Female | Professional U20 | Meters per minute | Unspecified | 34 International friendly matches | | | | | > 75% Vmax | |
| Zurutuza et al.[23] | GPS 10 Hz | GPS 10 Hz | Catapult | Minimax v.4.0 | Sprint v5.1.4 | 16 | Male | Semi-professional | Meters per minute | Unspecified | Seven microcycles are competitive with SSG, MSG, LSG, and SG. | | | < 60% Vmax | 60–80% Vmax | > 80% Vmax | |
| Zurutuza et al.[24] | GPS 10 Hz | GPS 10 Hz | Catapult | Minimax S4 | Sprint v5.1.4 | 15 | Male | Semi- Professional | Meters and percentage of distance covered | Unspecified | 20 training sessions and eight matches | | | | | > 80% Vmax | |
| Núñez-Sánchez et al.[25] | The sprint from a standing start with their front foot 0.5 m behind the start line whit GPS 15 Hz | GPS 15 Hz | GPSport | SPI-pro W2b | AMS-R1–2012.9 | 20 | Male | Semi-professional | Meters per minute | Unspecified | Four friendly matches | In this article, 10 ranges were stabilized, where the first level is the velocity < 10% of Vmax and the last level is > 90% of Vmax | | | | | |
| Scott and Lovell.[26] | Light gates positioned at 10 m intervals. Players adopted the split stance technique with the front foot positioned 0.5 m before the starting | MEMS 10 Hz | Catapult | Optimeye S5 | OpenField V. 1.14.0 | 22 | Female | Professional | Meters | Unspecified | 21 days training | | | > 50% Vmax | > 65% Vmax | | |
| Scott et al.[27] | Timing gates at 10 m | GPS 10 Hz | Catapult | Optimeye S5 | Unspecified | 136 | Female | Professional | Meters | Unspecified | 220 competitive matches | | | > 50% Vmax | > 65% Vmax | > 80% Vmax | |
| *Maximum speed in 20 m* | | | | | | | | | | | | | | | | | |
| Doncaster and Unnithan.[28] | From standing with GPS 10 Hz | GPS 10 Hz | Catapult | Unspecified | Sprint v5.1.0 | 17 | Male | Youth U14 | Meters | Unspecified | Three training matches | | | | > 50% Vmax | > 70% Vmax | > 90% Vmax |

*(continued)*

**Table 2.** (continued)

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | Type of displacement | Task | Speed categories Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Doncaster et al.[29] | From standing with GPS 10 Hz | GPS 10 Hz | Catapult | Unspecified | Catapult | 17 | Male | Youth U14 | Meters and meters per minute | Unspecified | Three training matches | | | | > 50% Vmax | > 70% Vmax | > 90% Vmax |
| Atan et al.[30] | 10 m flying to obtain a maximum speed of 20 m with GPS 15 Hz. By means of the individual Maximum Speed, the Average Speed for each group was calculated | GPS 15 Hz | GPSports | Unspecified | Team AMS V12 | 85 | Male | Youth U13 to U15 | Meters and meters per minute | Unspecified | Two competitive matches for each group. | U13 | 0–4 km/h | 4–8 km/h | 8–13 km/h | 13–18 km/h | >18 km/h |
| | | | | | | | | | | | | U14 | 0–4.5 km/h | 4.5–8.5 km/h | 8.5–13.5 km/h | 13.5–18.5 km/h | >18.5 km/h |
| | | | | | | | | | | | | U15 | 0–5 km/h | 5–9 km/h | 9–14 km/h | 14–19 km/h | >19 km/h |
| Harley et al.[31] | 10 m flying to obtain the maximum speed of 20 m with timing gates placed at 10 m and 20 m. Through the individual Maximum Speed, the Average Speed for each group was calculated | NdGPS 5 Hz | Catapult | MinimaxX | Unspecified | 112 | Male | Youth U12 to U16 | Meters and meters per minute | Unspecified | 14 competitive matches between all age groups | U16 | 0.46–1.8 m/s | 1.8–3.6 m/s | 3.6–5.04 m/s | 5.04–6.41 m/s | >6.41 m/s |
| | | | | | | | | | | | | U15 | 0.44–1.78 m/s | 1.78–3.56 m/s | 3.56–4.89 m/s | 4.89–6.22 m/s | >6.22 m/s |
| | | | | | | | | | | | | U14 | 0.4–1.59 m/s | 1.59–3.18 m/s | 3.18–4.37 m/s | 4.37–5.56 m/s | >5.56 m/s |
| | | | | | | | | | | | | U13 | 0.39–1.58 m/s | 1.58–3.16 m/s | 3.16–4.34 m/s | 4.34–5.53 m/s | >5.53 m/s |
| | | | | | | | | | | | | U12 | 0.38–1.52 m/s | 1.52–3.04 m/s | 3.04–4.18 m/s | 4.18–5.52 m/s | >5.52 m/s |
| Saward et al.[32] | Participants completed a 20 m sprint test with a split at 10 m using infrared photoelectric cells | GPS 1 Hz or 5 Hz | GPSports | SPI Elite or SPI Pro | Team AMS, v 2.1 | 263 | Male | Youth U9 to U19 | Meters and percentage of distance covered | Unspecified | Players were assessed in 1–29 competitive inter-academy matches, resulting in a total of 988 player matches. | | | < 45% Vmax | > 45% Vmax | > 75% Vmax | |
| Tan et al.[33] | Using electronic-light timing gates | GPS 5 Hz | Catapult | MiniMax | Logan Plus | 10 | Female | Professional | Meters, meters per minute, and mean speed | Unspecified | Three competitive matches | | | | < 75% Vmax | > 75% Vmax | |
| Nakamura et al.[34] | They were recorded by photocells adjusted to a height of 1 m, from a standing position 0.3 m behind the start line | GPS 5 Hz | GPSports | SPI Elite | Unspecified | 11 | Female | Professional | Number of sprints, meters, meter per minute, and duration (s) of each sprint | Unspecified | 10 matches | | | | | | > 90% Vmax |

(continued)

**Table 2.** (continued)

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | Type of displacement | Task | Speed categories Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *YYIR1 for MAS and peak speed reached during collection for MSS. The ASR was determined as the difference between MSS and MAS* | | | | | | | | | | | | | | | | | |
| Rago et al.[35] | GPS. The peak speed reached during training was assumed to be the MSS | GPS 10 Hz | Qstarz | BT-Q1000 Ex | Unspecified | 20 | Male | Professional | Meters | Unspecified | 45 training sessions and three friendly matches | | | < 80% MAS | 80–99.9% MAS | 100% MAS –29% ASR | ≥ 30% ASR – 100% MSS |
| Rago et al.[36] | GPS. The peak speed reached during training was assumed to be the MSS | GPS 10 Hz | Qstarz | BT-Q1000 Ex | Unspecified | 13 | Male | Professional | Meters | Unspecified | 42 training sessions and three friendly matches | | | | 80–99.9% MAS | 100%MAS – 29% ASR | ≥ 30% ASR |
| *Vam-Eval maximal incremental running test for MAS, maximum speed in 40 m for MSS, and the ASR was determined as the difference between MSS and MAS* | | | | | | | | | | | | | | | | | |
| Mendez-Villanueva et al.[37] | Dual-beam electronic timing gates set at 10-m intervals from standing start with their front foot 0.5 m behind the first timing gate | GPS 1 Hz | GPSports | SPI Elite | Unspecified | 103 | Male | Youth U13 to U18 | Meters | Unspecified | 42 competitive matches | | 60% of MAS | 61–80% of MAS | 81–100% of MAS | > 101% of MAS to 30% of ASR | >31% of ASR |
| Hunter et al.[19] | Timing gates at 10, 20, 30, and 40 m | GPS 5 Hz | Catapult | MinimaxX | Unspecified | 12 | Male | Youth U18 | Meters and percentage of distance covered | Unspecified | 22 competitive matches | | | < 79% MAS < 79% MAS | 80–99% MAS 80–99% MAS | 100–139% MAS 100 MAS–29% ASR | Ø 140% MAS > 30% ASR |
| Abbott et al.[38] | The fastest speed recorded over any 10 m sector, using electronic light gates at 10, 20, 30, and 40 m | GPS 10 Hz | Catapult | OptimEye S5B, V. 7.18 | Sprint 5.1.5 | 37 | Male | Professional U23 | Meters | Unspecified | 44 competitive matches | | | | | 100% MAS – 30% ASR | > 30% ASR |
| Abbott et al.[39] | Dual-beam electronic timing gates set at 10-m intervals from standing | GPS 10 Hz | Catapult | Minimax v4.0 | Sprint 5.1.5 | 46 | Male | Professional U23 | Meters and meters per minute | Unspecified | 22 matches and 39 training sessions | | | | | 100% MAS – 30% ASR | > 30% ASR |
| *Vam-Eval maximal incremental running test* | | | | | | | | | | | | | | | | | |
| Scott and Lovell[26] | Unspecified | MEMS 10 Hz | Catapult | Optimeye S5 | OpenField V. 1.14.0 | 22 | Female | Professional | Meters | Unspecified | 21 days training | | | | | < 80% MAS | 80–100% MAS |
| *Individual lactate threshold and maximum speed in 30 or 40 m* | | | | | | | | | | | | | | | | | |
| Skalska et al.[40] | GPS 10 Hz in 30 m | GPS 10 Hz | Catapult | MinimaxX V4.0 | Sprint 5.0 | 36 | Male | Youth U18 | Meters and percentage of distance covered | Unspecified | 8-week training during preseason | 0–1 m/s | 1–2 m/s | >2 m/s–V/LT | V/LT–80% Vmax | > 80% Vmax | |
| Jastrzębski and Radzimińsk.[41] | GPS 10 Hz in 40 m | GPS 10 Hz | Catapult | minimaxXV.4.0 | Sprint 5.0 | 13 | Male | Professional | Meters and percentage of distance covered | Unspecified | 8 SSG, 4 × 4 and 5 × 5. | 0–1 m/s | 1–2 m/s | 2 m/s-V/LT | V/LT–80% Vmax | > 80% Vmax | |
| Jastrzębski and Radzimińsk.[14] | GPS 10 Hz in 40 m | 10 Hz | Catapult | minimaX 4.0 | Sprint5.0 | 16, 8 and 8. | Female and male | Professional | Meters | Unspecified | 5–7 training sessions and one league game. SSG, 4 × 4. | 0–1 m/s | 1–2 m/s | 2 m/s – V/LT | V/LT–80% Vmax | >80% Vmax | |
| *Final velocity of the 30:15 intermittent fitness test and maximum speed in 40 m. The ASR was determined as the difference between MSS and MAS* | | | | | | | | | | | | | | | | | |

*(continued)*

**Table 2.** (continued)

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | Type of displacement | Task | Speed categories Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tomazoli et al.[20] | Timing gates at 10 m, front foot 0.5 m behind the first timing gate | GPS 10 Hz | Catapult | Optimeye S5 | Sprint 5.0.6 | 12 | Male | Youth U19 | Meters | Unspecified | 10 matches competitive | | | < 79% MAS | 80–99% MAS | 100 MAS–29% ASR | 30% ASR –MSS |
| Trewin et al.[42] | Unspecified | GPS 10 Hz | Catapult | Minimax S4 | Sprint 5.1. | 45 | Female | Professional | Meters and meters per minute | Unspecified | Player movement data was tracked across 5 years (2012–2016) and 55 International matches | | | | >4.58 m/s Team average of MAS | >5.55 m/s Team average of MSS | |
| Scott et al.[27] | Timing gates at 10 m for the sprint of 40. | GPS 10 Hz | Catapult | OPTIMEYE S5 | Unspecified | 136 | Female | Professional | Meters | Unspecified | 220 competitive matches | | | | > 60% MAS | > 80% MAS | > 30% ASR |
| *Final velocity of the 30:15 intermittent fitness test or YOYO Intermittent Recovery Level 1 test MAS* | | | | | | | | | | | | | | | | | |
| Buchheit et al.[43] | Unspecified | GPS 10 Hz | Catapult | MinimaxX Team Sports 4.0 | Unspecified | 13 | Male | Youth U17 and U18 | Meters | Unspecified | Five competitive matches | | | | >80% VFy-y | | |
| Tomazoli et al.[20] | Unspecified | GPS 10 Hz | Catapult | Optimeye S5 | Sprint 5.0.6 | 12 | Male | Youth U19 | Meters | Unspecified | 10 competitive matches | | | <79% MAS | 80–99% MAS | 100–139% MAS | ≥140% MAS |
| Madison et al.[44] | Unspecified | GPS 18 Hz | StatSports | Apex, V.2.1.0.4 | StatSports Apex | 10 | Male | Semi-professional | Meters | Unspecified | Four sessions during four week period. SSG 3 × 3 and 4 × 4 | < 25% MSS | 25–50% MSS | 50–75% MSS | 75–100% MSS | 100–125% MSS | > 125% MSS |
| Scott and Lovell.[26] | Unspecified | MEMS 10 Hz | Catapult | Optimeye S5 | OpenField V. 1.14.0 | 22 | Female | Professional | Meters | Unspecified | 21 days training | | | | >80% VFy-y | >100% VFy-y | |
| *Maximum speed in 10 m* | | | | | | | | | | | | | | | | | |
| Goto et al.[45] | Photoelectric timing gate was placed at 0, 5 and 10 m. The players sprinted from 1 m behind the first timing gate | GPS 1 Hz | GPSport | SPI elite | Team AMS V.1.2 | 81 | Male | Youth U11 to U16 | Meters | Unspecified | The matches were part of the regular series of inter-academy matches between Premier League Academies during a season | INDIVIDUAL (Slowest or Fastest) | 0–1.1 or 0–1.5 m/s | 1.2–2.2 or 1.6–3 m/s | 2.3–3.3 or 3.1–4.5 m/s | 3.4–4.4 or 4.6–6 m/s | >4.4 or >6 m/s |
| - | | | | | | | | | | | | Squad speed zone | | | | | |
| | | | | | | | | | | | | U11 | 0–1.1 m/s | 1.2–2.1 m/s | 2.2–3.2 m/s | 3.3–4.2 m/s | >4.2 m/s |
| | | | | | | | | | | | | U12 | 0–1.1 m/s | 1.2–2.2 m/s | 2.3–3.2 m/s | 3.3–4.3 m/s | >4.3 m/s |
| | | | | | | | | | | | | U13 | 0–1.1 m/s | 1.2–2.2 m/s | 2.3–3.3 m/s | 3.4–4.4 m/s | >4.4 m/s |
| | | | | | | | | | | | | U14 | 0–1.2 m/s | 1.3–2.3 m/s | 2.4–3.5 m/s | 3.6–4.6 m/s | >4.6 m/s |
| | | | | | | | | | | | | U15 and U16 | 0–1.2 m/s | 1.3–2.4 m/s | 2.5–3.7 m/s | 3.8–4.9 m/s | >4.9 m/s |
| Goto et al.[46] | Photoelectric timing gate was placed at 0, 5, and 10 m. The players sprinted from 1 m behind the first timing gate | GPS 1 Hz | GPSport | SPI elite | Team AMS V.1.2 | 80 | Male | Youth U9 to U16 | Meters and percentage of distance covered | Unspecified | The matches were part of the regular series of inter14 academy matches between Premier League Academies during a season | U9 | 0.0–1.0 m/s | 1.1–2 m/s | 2.1–3.1 m/s | 3.2–4.1 m/s | > 4.1 m/s |
| | | | | | | | | | | | | U10 | 0.0–1.0 m/s | 1.1–2.1 m/s | 2.2–3.1 m/s | 3.2–4.2 m/s | >4.2 m/s |
| | | | | | | | | | | | | U11 | 0.0–1.1 m/S | 1.2–2.1 m/s | 2.2–3.2 m/s | 3.3–4.2 m/s | >4.2 m/s |

(continued)

**Table 2.** (continued)

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | Type of displacement | Task | Speed categories Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | U12 | 0.0–1.1 m/S | 1.2–2.2 m/s | 2.3–3.2 m/s | 3.3–4.3 m/s | > 4.3 m/s |
| | | | | | | | | | | | | U13 | 0.0–1.1 m/S | 1.2–2.2 m/S | 2.3–3.3 m/s | 3.4–4.4 m/s | > 4.4 m/s |
| | | | | | | | | | | | | U14 | 0.0–1.2 m/S | 1.3–2.3 m/s | 2.4–3.5 m/s | 3.6–4.6 m/s | >4.6 m/s |
| | | | | | | | | | | | | U15 and U16 | 0.0–1.2 m/S | 1.3–2.4 m/s | 2.5–3.7 m/s | 3.8–4.9 m/s | >4.9 m/s |
| *Maximum speed recorded by EPTS during matches* | | | | | | | | | | | | | | | | | |
| Aquino et al.[47] | GPS 5 Hz | GPS 5 Hz | QSTARZ | BT-Q1300ST | QSport | 51 | Male | Youth U11 to U20 | Meters | Unspecified | SSG 6 × 6 or two official matches: all matches were performed during the in-competitive season. | | | | > 60% Vmax | | |
| Palucci Vieira et al.[48] | Video 30 Hz | Video 30 Hz | Woodman Labs | GOPRO HERO 3 + Black Edition | MathWorks | 120 | Male | Youth, U13, U15, U17, U20, and Professional | Meters, meters per minute, and the average distance traveled above this speed parameter (> 70% MSS) | Unspecified | 12 matches | | | | | > 70% Vmax | |
| Springham et al.[49] | GPS 10 Hz and MEMS | GPS 10 Hz and MEMS | Statsports | Viper 2 | Statsports Viper | 18 | Male | Professional | Meters, meters per minute, and number of sprints. | Unspecified | 48 competitive matches | | | | | > 80% Vmax | |
| *Conconi test* | | | | | | | | | | | | | | | | | |
| Vigne et al.[50] | Treadmill. | multi-camera | SICS | Unspecified | Unspecified | 25 | Male | Professional | Meters | Unspecified | 30 home matches | <5 km/h | 5–13 km/h | 13–16 km/h speed below the anaerobic threshold | 16–19 km/h speed above the anaerobic threshold | >19 km/h | |

Vmax: maximum speed; ASR: anaerobic reserve speed; MAS: maximum aerobic speed; MSS: maximum sprint speed; V/LT: lactate threshold velocity; VFy-y: final speed in YOYO Intermittent Recovery Level 1 test; GPS: global positioning system; Hz: hertz; M: meters; km/h: kilometers per hour; m/s: meters per second; SSG: small sided games; MSG: moderate sided games; LSG: longer sided games; SG: simulated games.

**Table 3.** Classification of acceleration/deceleration categories.

| Ref. | Obtaining the threshold | EPTS | Manufacturer | Branch | Software | Sample | Sex | Level | Displacement measurement | type of displacement | Task | Speed categories Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Repeated sprint exercise (RSE) was 3 sets of 7 × 30 m sprints with 25 s and 3 min recovery between sprints placed at the start and end of the mentioned distance. Maximum acceleration (MA) 30 m and sub-maximum (SA) 10 m* | | | | | | | | | | | | | | | | | |
| Beato and Drust[51] | Infrared timing gates in 10 m and 30 m | GPS 10 Hz | Statsport | Viper | Unspecified | 16 | Male | Amateur | Meters and meters per minute | Linear | 3 × 7 × 30 m | | | | | >SA | >MA |
| *40 m sprint test* | | | | | | | | | | | | | | | | | |
| Núñez et al.[52] | GPS 15 Hz, from a standing start with their front foot 0.5 m behind the start line | GPS 15 Hz | GPSport | SPI-pro W2b | Team AMSR1–2012.9 | 20 | Male | Semi-professional | The number of accelerations, the % of individual maximal accelerations, and the mean distance covered | Unspecified | Four friendly matches | | > 50% MA | 0–13 km/h and did not reach 18 km/h | 0–13 km/h and reached 18 km/h | 13–18 km/h | >18 km/h |
| Abbott et al.[12] | GPS 10 Hz | GPS 10 Hz | Catapult | OptimEye S5B V.7.1.8 | Sprint 5.1.5 | 31 | Male | Professional U19 | Meters | Unspecified | 23 training sessions and four friendly matches | | | 25–50% MA | 50–75% MA | >75% MA | |
| Abbott et al.[38] | GPS 10 Hz | GPS 10 Hz | Catapult | OptimEye S5B, V. 7.18 | Sprint 5.1.5 | 37 | Male | Professional U23 | Meters | Unspecified | 44 competitive matches | | | | 50–75% MA | >75% MA | |
| *Acceleration over 10 m during a 40 m sprint test* | | | | | | | | | | | | | | | | | |
| Trewin et al.[42] | GPS 10 Hz | GPS 10 Hz | Catapult | Minimax S4 | Sprint 5.1 | 45 | Female | Professional | Meters and meters per minute | Unspecified | Player movement data was tracked across 5 years (2012–2016) and 55 International matches | | | | | > 80% MA | |
| *Acceleration 10 m sprint test* | | | | | | | | | | | | | | | | | |
| Meylan et al.[22] | GPS 10 Hz | GPS 10 Hz | Catapult | Minimax S4 | Sprint 5.1.0.1 | 20 | Female | Professional U20 | Meters per minute | Unspecified | 34 International friendly matches | | | | | > 80% MA team average | |
| *Acceleration over 5 m during a 40 m sprint test* | | | | | | | | | | | | | | | | | |
| Serpiello et al.[53] | GPS 10 Hz | GPS 10 Hz | Catapult | Optimeye S5 | Sprint 5.1.7 | 36 | Male | Youth U16 | The number, average recovery, and average duration of RHAA | Unspecified | 41 competitive matches | | | | > 70% MA team average | > 80% MA team average | |

MA: maximum acceleration; SA: sub-maximum acceleration; RSE: Repeated sprint exercise; RHAA: Repeated High Acceleration Ability; GPS: global positioning system; Hz: hertz; M: meters; km/h: kilometers per hour.

performance,[64] whilst the frequency to which fitness components need re-assessment, aiming at adjust thresholds accounting for those time-related changes, seemingly also unknown.[65] Such results collectively reinforce the lack of full confidence and consensus in applying a 40 m linear sprint test to obtain "anchors" of speed/acceleration thresholds. Soccer demands generally involve energetic costs in changing direction, unorthodox displacements, and physical impacts,[27] which might be difficult to capture in standard outcome metrics derived from traditional linear sprint tests.

In an attempt to overcome possible limitations of a single bout maximal linear sprint as mentioned above, also considering the lowest weight it may have to a dataset of soccer external load measures collected in official matches[66] likely given the one-off nature of MSS in soccer,[67] some authors employed test protocols more prolonged in nature. These included Yo-Yo Intermittent Recovery Test level 1, Vam-Eval maximal incremental running test, 30:15 Intermittent Fitness test (30–$15_{IFT}$), and Conconi test performed on a treadmill. Despite having large-to-very large associations with match-play running performance either relating to the total distance covered or high-intensity running,[56] graded exhaustive treadmill tests represent severe limitations to most clubs given time requirements, costs, and player's motivation, implying a need to consider other solutions with more prominent practical value such as field-based assessments.[68] Instead, a trend of a recent increase in the use of anaerobic speed reserve (ASR) as a threshold was noted here for approximately one-fourth of all studies included, of which most were published over the last three years.[20,27,35,36,38,39,42] The ASR is a compound of two markers, that is, computed as the difference between player MSS and maximal aerobic speed, thus combining in a single index the individual's fitness characteristics observed on a separate all-out sprint effort and those from speed attained at maximal oxygen consumption ($v\dot{V}O_{2max}$). Such metrics seem to benefit from creating thresholds since players showing similar $v\dot{V}O_{2max}$ (not uncommon across outfield playing positions)[69] may not have a matched MSS performance.[57,70] In these conditions, the ability to cope with a given load, in particular in high-intensity domain, would depend on the proportion of ASR reached[71] rather than looking solely for a percentage of the former fitness indicator. Again, one of the issues which arguably preclude unrestricted recommendation of ASR to date is no empirical evidence supporting its construct validity (e.g. 30–$15_{IFT}$ performance vs. match-play running outputs; see also).[72]

Regardless of whether there is currently an unsolved debate, since studies recommend using,[54,62,73] maybe,[19,65,74] or others suggest avoid[26,56,59] fitness testing when defining speed thresholds, a lack of standardization was observed here in both, determinations of individualized speed/acceleration categories representing distinct workload demands and the parameters used to extract a given anchor. To be explicit and using the 40 m sprint test as an example, timing gates at the start, 10 and 40 m[22]; 30 and 40 m[21]; 10-m intervals[17–20,26,27]; or MSS attained independent of location[23,24,52] were among methods used. Furthermore, following these procedures, the levels for "higher" intensity recorded were defined considering 50–60%,[52] 80–100%,[19,20] > 61%,[17,18,21] > 65%,[26] > 75%,[22] > 80%,[23,24,27] or > 90%[52] of MSS. It makes it difficult to directly compare results across literature and provide systematic concluding remarks on the most appropriate one. To assist move beyond this question, intervention designs assessing the practical effect of individualized thresholds in various aspects (e.g. fitness, injury, and match performance) are recommended as opposed to common application/comparison of methods.[73]

Finally, particular attention should also be paid to the technology employed in obtaining performance indices often used in originating the movement intensity thresholds. Ten-Hertz GPS was identified as the most common device used to determine velocity/acceleration thresholds during testing routines and collect external task loads. It is recognized that these generally provide valid measures to assess distance and velocity in linear movements and during simulations of running characteristics about team sports, while no additional benefits of a nearby higher acquisition frequency can exist[6,75] However, during acceleration occurrences above 4 m/s² limits, accuracy using 10 Hz GPS is not always ensured.[76] One can argue that there is not a proper "gold standard" available in computing external loads such as running performance[17,77,78] while others recognize high-speed three-dimensional motion capture systems.[6] Context, logistics, and the need for a qualified team with the how-to for data treatment of image sequences are among potential constraints on using the latter. Examples include the costs involved, set-up configuration, and time-consuming nature which collectively make difficult application of video-based tracking systems in practice difficult. It is also observed in the present analysis because only one study using the latter method was found (see Table 2). Regardless of the EPTS or IMU used, an important aspect to keep in mind is that the measurement error must be evaluated by taking into account the specific location in which they were collected (see a review: Palucci Vieira et al.[59]) and only two studies included in our analysis did so (Aquino et al.[47]; Palucci Vieira et al.[48]) most cited data from previous research or reported only horizontal precision dilution calculated by the software's proprietary. In summary, interpretation of the current evidence on velocity thresholds using 10 Hz GPS may be reliable, not on acceleration thresholds, because more explosive movements may require higher hertz devices. Even so, more is needed with quality research control protocols that allow researchers and sports professionals to obtain valid and reliable information.

In brief, once the analysis of all the articles that contain a justification of the speed threshold has been carried out and given the heterogeneity shown, it can be said that it is no consensus in the literature to know which test is the most indicated or which percentages are the most suitable for setting intensity within speed thresholds. However, those accelerations above 80% of each player's maximum acceleration are a standard indicator in the literature.

## Limitations

A number of potential limitations should be recognized to the methods used in the present review as well as the derived implications: (1) inclusion of studies only in English, which may have resulted in a loss of evidence on the topic when published in other languages; (2) consideration of all works regardless of whether it varies concerning the quality of evidence; (3) lack of a quantitative synthesis of extracted information, which is partly attributed to a substantial heterogeneity of methods used across included articles; (4) only eight studies[17,27,30–32,37,45,46,48] were conducted with a minimum of 80 players as per previous recommendations to ensure sufficient statistical power[79]; (5) evidence may apply to a greater extent to youth male players rather than senior male and women's soccer and finally, (6) despite the probed importance of curvilinear movements,[80] these were not explicitly determined in any of the reviewed studies.

## Conclusion

In short, a 40 m sprint test performed on-field was identified as the preferred method to create individualized speed or acceleration thresholds in depicting players' external load in soccer. While the benefits of drawing thresholds from a single fitness indicator such as maximal sprinting performance are accompanied by several limitations (e.g. may lack superior sensitivity to profile dose–response to training-induced changes), a rapid increase was identified in recent years, suggesting the use of compound measures such as anaerobic speed reserve. However, in either case, the construct validity of fitness data to predict match-play running performance is not current. Also, the lack of standardization on test procedures and threshold zones established and the low sampling frequency in studies computing acceleration and deceleration demands defy practical applications. Finally, extending previous research using match data to obtain thresholds is still required to overcome potential issues from testing outside the game context. Otherwise, intervention works are needed to confirm the value of individualizations based on fitness status.

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