The role of acceleration and deceleration in agility, change of direction speed and running in soccer players' movements

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“We are like butterflies who flutter for a day and think it is forever.”

Carl Sagan, Cosmos (1980)

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Abstract

Monitoring accelerations and decelerations in soccer activities entails specific challenges for practitioners and researchers. This thesis aims to provide a new proposal to monitor accelerations and decelerations, by addressing those challenges: the use of minimum effort duration, the utilization of fixed and arbitrary thresholds, and by highlighting the importance of accelerations and decelerations efforts in agility, change of direction speed, and speed displacements. Two (n=2) systematic reviews and nine (n=9) empiric scientific studies were developed. During the empiric studies development, training sessions (ranging from 19 to 85) and matches (ranging from 4 to 84) from five (n=5) different clubs from three (n=3) different countries were monitored with GNSS devices. Additionally, three (n=3) field tests were conducted to assess the maximum acceleration (5 m), maximum sprint (30 m), and the pro-agility test (5-10-5). Accelerations and decelerations efforts should be assessed without minimum effort duration as it can be detrimental to a correct load assessment, especially considering decelerations. Additionally, to classify efforts intensities, an individual approach is recommended by considering the players' individuality and starting speeds. Match imposed higher demands than other activities but combining SSG and compensation drills can be a good strategy for compensation sessions (MD+1), regarding acceleration and deceleration demands; and rondos should be carefully used as it can elicit high intensity accelerations and decelerations demands. During warm-ups, reaction speed can help players develop agility, without imposing high decelerations demands; run drills can offer a relatively low demand to players, especially as strategy on recovery sessions (MD+1); and finally, speed drills expose players to high-intensity demands, being from accelerations and decelerations efforts, or from high-speed displacements. Speed assessments should also consider players individuality since absolute thresholds can represent different intensities for different players. Conducting field tests should consider the real-scenario (i.e. short accelerations, starting from high speeds). Finally, to be successful at a change of direction task, players need to quickly accelerate and decelerate, and the pro-agility test appears to mimic peak accelerations registered during matches.

Keywords: global-position system, mesocycle, microcycle, sprint, training load, velocity.

List of Abbreviations

ACC – acceleration

ANOVA – analysis of variance

CD – central defenders

CI – confidence interval

CV – coefficient of variation

CM – central midfielders

COD – change of direction

CODS – change of direction speed

DEC – deceleration

FB – fullbacks

FIFA – Fédération Internationale de Football Association

FW – forwards

GK – goalkeepers

GNSS – Global navigation satellite system

GPS – global positioning systems

HR – Heart rate

HSR – high-speed running

Hz – Hertz

MD-1 – match day minus one day

MD-2 – match day minus two days

MD-3 – match day minus three days

MD-4 – match day minus four days

MD-5 – match day minus five days

PRISMA – Preferred Reporting Items for Systematic Review and Meta-analysis

RPE – Rate of Perceived Exertion

SSG – small-sided games

U23 – under 23 years old

UEFA – Union of European Football Associations

WM – wide midfielders

WU – Warm-up

CHAPTER I: INTRODUCTION

Soccer[1] is an intermittent sport, with players alternating activities every 4-6 seconds (1), in addition to changing intensities. From the 9 to 14 km covered during each match, 2-3% is covered at speeds > 25 $km \cdot h^{-1}$ (2). Due to the constant alternation of activities, players spent 18% of matches accelerating and decelerating[2] (> 1 $m \cdot s^{-2}$) (2). Additionally, during matches players perform more than 700 changes of direction – especially with cutting angles inferior to 90º (2). This information shows the usual work performed by players, highlighting the intermittence of the sport. As so, assessing variables such as total distance, may mislead practitioners by overweighting distance covered at very low speeds – such as walking. Furthermore, considering that the work:rest ratio (time in activities versus time spent resting) can range from 1:12 ratio to 1:2 (a more intense period of matches) (2), recovery time can also influence the overall load if efforts intensities are disregarded during load assessment. Interestingly, this perception appears to be present during training sessions assessments, as reported by Akenhead and Nassis study (3). In that study, the authors questioned high-level clubs regarding load monitoring, reporting that most clubs used acceleration variables (peak acceleration, velocity change load, and accelerations above a specific threshold) to monitor training sessions. However, the same study also reported that total distance was the variable most used to assess match demands.

Although no clear reason has been presented to justify the choice of total distance to assess load, the lack experience, time, or human resources to manage high volumes of data can inhibit clubs to choose other variables – which account for the sport intermittency. Additionally, public exposure from elite competitions can mystify the importance of total distance. For instance, during a UEFA Champions League match, total distance statistics are often presented to the audience. In media context, this makes sense, because this is a very simple data to understand by the non-specialized audience. It is quite easy to understand if the team A (or player A) covered more distance than the team B (or player B). However, explaining acceleration and deceleration thresholds to the audience would most certainly elicit confusion, even if providing crucial information

[1] In scientific research, the term soccer is most frequently used than the term football. Since football can be confused with American Football or Australian Football (which differ from the association football), authors predominately refer to association football as soccer. However, some scientific journals, by being European based, use the term football to refer to association football.

[2] Considering that acceleration is defined as the rate of change of velocity per unit of time (in this case, a positive change, or an increase in velocity) deceleration can also be called an acceleration (in this case, a negative change, or a decrease in velocity). Importantly, in biomechanics, a negative acceleration can be an acceleration in the negative direction.

regarding the work performed by players. Di Salvo and colleagues' study (4) provides an important reflection regarding measurement variables efficacy to correctly assess demands. During their study, the authors analyzed Premier League match demands, reporting that players covered around 35% of their total distance by walking pace (0.2 $km \cdot h^{-1} < 7.2\ km \cdot h^{-1}$). As so, players covered a high percentage of their total distance at a low intensity effort, that could even relate to active rest situations or insignificant displacements. Therefore, it is no surprise that scientific research has increasingly investigated other variables, mainly accelerations and decelerations (5).

Interestingly, the increased interest in these activities will probably continue in the upcoming years, since tactical evolutions (high-intensity pressing, counter-pressing and counterattacking) will surely require short and intense accelerations and decelerations from soccer players (6). This should be faced with special consideration by practitioners, because increasing these efforts leads to certain consequences. First, fatigue is expected to increase because accelerations elicit elevated power outputs (1000 Watts) and increase the energy depletion (7). Secondly, decelerations have been linked with increase injury risk, especially if the athletes are not accustomed (and therefore unprepared) to these efforts (8,9). Thirdly, since change of direction and agility (reaction to a stimulus) are dependent on these movements, athletes must be able to safely accelerate and – especially – decelerate as that can differentiate athletes with higher injury risk (10,11).

In scientific research, there are two main paths to assess accelerations and decelerations during training sessions or during matches: horizontal movements defined simply as accelerations and decelerations; and assessing movements in a triaxial approach which is named as PlayerLoad – combines accelerations produced in three planes of body movement and is measured with a triaxial accelerometer (12). While PlayerLoad data is retrieved from accelerometers, which are traditionally incorporated in global position systems (GPS) devices, assessing horizontal movements does not require triaxial accelerometers (5,13). The main advantage of PlayerLoad is the inclusion of jump and rotations movements, which are excluded from the horizontal movements approach. However, since PlayerLoad derives from one equation, combining accelerations produced in three planes of body movement, distinguishing efforts from one specific plane of movement becomes difficult. As so, most scientific studies focus the acceleration and deceleration monitoring process by assessing horizontal movements, with GPS devices.

GPS can collect acceleration and deceleration data by calculating the change in velocity (calculated by the distance – change in position according to latitude and longitude – over time) over the change in time (14). In this method, the position (latitude and longitude) is calculated with information of the distance of each satellite to the device and then triangulating the devices' location. Then, distance can be calculated with the change in position with each signal. With distance and time, velocity (distance over time), and accelerations (change of velocity over change of time) can be calculated. Traditionally, accelerations and decelerations are calculated by the Doppler shift[3] (the change in frequency of the satellite emitted periodic signal), due to the higher level of precision in comparison with previously mentioned method (positional calculations) (14,15). Additionally, there are two important considerations to refer when collecting this data: sampling rate and minimum effort duration. The sampling rate refers to the number of data points that are collect for each second (i.e., a sampling rate of 10 Hz collects 10 data points per second) (16). The minimum effort duration refers to the minimum duration that the effort[4] must exceed to be counted (i.e., a minimum effort duration of 0.5 seconds means that the acceleration needs to be sustained for at least 0.5 seconds to be counted) (13,17). These considerations place practitioners with important decisions to make before collecting data. First, higher sampling rates, can increase the measurements accuracy (16,18) but can also trigger data noise (by classifying a single effort as two or more efforts) (5,17). And secondly, there is no scientific consensus on what the most appropriate minimum effort duration should be use (13). This represents an important challenge to researchers and practitioners because they can potentially report different demands by just simply altering the minimum effort duration.

After collecting the data, practitioners also need to decide how to classify the effort intensity. There are three main challenges when classifying accelerations intensities. First, previous research has presented different (and arbitrary) thresholds that usually replicates values used in the past (19,20). Secondly, the same effort magnitude can be classified with moderate (21) or high (22) intensity, depending on what threshold

[3] The Doppler shift is named after the physicist Christian Doppler, who described the process of increase or decrease of starlight as dependent on the relative movement of the star. One common example of the Doppler shift is the increase and decrease sound of a passing car, when listened by a person standing at the side of the road.

[4] The minimum effort duration can be applied to accelerations, decelerations, or other displacements. For example, some authors may consider a sprint effort if a player sustains a pre-established threshold for a specific amount of time.

is chosen. Thirdly, if an absolute value is chosen, the player individuality is disregarded. That is, a specific intensity for one player could represent a different intensity for another (23). And fourthly, the effort starting speed could also influence the effort magnitude and, therefore, the intensity classification. Addressing this, Sonderegger and colleagues (24) suggested that the acceleration intensity (high intensity: >75% of the maximal; moderate: >50%; low: >25%); and very low: <25%) should be calculated as the percentage of the maximal observed acceleration and the maximal voluntary acceleration that could be achieved for each starting speed. These authors divided the starting speed in three intervals: standing start, trotting (6.0 $km \cdot h^{-1}$), jogging (10.8 $km \cdot h^{-1}$), and running (15.0 $km \cdot h^{-1}$) and showed that the acceleration capacity decreases with increases in starting speed. This proposal presents one additional advantage in comparison to the absolute method: although efforts below 1 or 2 $m \cdot s^{-2}$ are normally excluded from analysis (25–28), they can represent significant intensities at higher starting speeds. However, no consensus exists to what speed intervals should be used (important to starting speeds intervals), with authors replicating previous studies (19). Additionally, the percentage method, being an exciting proposal to assess intensities, does not include decelerations – due to the difficulty to access a maximal voluntary deceleration – and requires field tests to collect the maximal voluntary acceleration.

Unfortunately, the percentage method is still scarce in the literature. Several papers collect and analyze acceleration and deceleration data with absolute and arbitrary thresholds. Within these studies, acceleration and deceleration demands in soccer players, are mainly analyzed during matches (29), training sessions (30), and during different small-sided games (SSG) formats (31–33). However, training sessions are not limited to SSG, as practitioners also apply different exercises to their players. For example, warm-ups elicited fewer relative accelerations and decelerations than matches and friendly matches (34). This is particularly important, because warm-up precedes all activities, being matches or training sessions. However, little is known regarding the demands of these activities, especially considering different warm-ups protocols. After warm-ups, practitioners usually vary the training exercises to avoid training monotony and increase players motivation. However, since most studies focuses on SSG, little is known about other exercises. One exception was presented by Giménez and colleagues (31), by identifying circuit training as the least demanding exercise, in comparison with different SSG variations and friendly matches. Playing positions are also frequently included in scientific research, with previous studies reporting differences between positions (32,35). However, goalkeepers are usually excluded from these studies due to the particularity of the position. Nevertheless, this position is also exposed to specific demands that should be understood. One study analyzed these demands regarding goalkeepers demands during SSG (36), which excludes the specific training usually performed by goalkeepers.

Besides using arbitrary thresholds instead of individualizing efforts, previous studies also disregarded speed at which accelerations and decelerations occur. As previously stated, speed and accelerations have been previously related with the percentage intensity method proposed by Sonderegger and colleagues (24), which highlighted that the acceleration capacity decreases when the acceleration starting speed is higher. However, the potential influence of the starting speed on how players express decelerations remains unclear. Increasingly, if players achieve a specific speed, they need to accelerate to reach it and decelerate to return to lower speeds. This is often disregarded with approaches assessing distance or time spent above a specific threshold. One clear example of the importance of accelerations in speed is the 100 meters race: in the world record race, Usain Bolt accelerated for 7.1 seconds until reaching his maximal speed (~ 45 $km{\cdot}h^{-1}$) (37). Considering that soccer is an interment sport where players need to change their speed rapidly, the importance of accelerations and decelerations are probably even more important. However, little is known considering how athletes reach specific thresholds (such as the sprint threshold [> 25.2 $km{\cdot}h^{-1}$]) or their peak speed. Additionally, since players do not spend much time at high speeds (4), how players leave that thresholds could play an important role in the deceleration magnitude.

Besides reaching and leaving high speeds, players can also be exposed to short but intense demands, because, during matches, players alternate activities constantly, including changes of directions. Specifically, players perform hundreds (> 700) of changes of directions, most of them with cutting angles < 90º (2). These efforts induce neuromuscular fatigue that can last up to 72h post-match (38). Moreover, around 100 changes of directions have high cutting angles (90-180º) (39), which expose players at higher braking forces (10). While performing a change of direction with an elevated cutting angle, players need to reduce their speed to zero before changing direction, and rapidly accelerate (40). Surprisingly, most change of direction studies focuses on performance (time) and not on accelerations and decelerations contributions. One study (41) compared acceleration and deceleration peak magnitudes between two different change of directions tasks, with reduce (45º) and elevated (90º) cutting angle, with the authors reporting higher peak decelerations and lower peak accelerations during high cutting angles. This is probably related to the high importance of horizontal braking forces during high cutting angle change of directions tasks (42). Since changes of directions are usually assessed with time gates (43), the role of accelerations and decelerations end up disregard. That is, the monitoring process of matches and training sessions is not replicated during change of direction tests performances. However, this could reveal important information for practitioners, helping analyze the players' capabilities to decelerate and accelerate during change of direction tasks.

CHAPTER II: OBJECTIVES

2.1. General and Specific Objectives

The main objective of this thesis was to investigate the role of accelerations and decelerations in soccer, by providing a new method to consider acceleration and deceleration demands, which accounts for high-intensity running displacements, and agility and change of direction efforts. To achieve this objective eleven specific objectives were established:

- Present a comprehensive analysis about internal and external training load across a soccer microcycle, considering the different methods used to assess load.
- Summarize the current scientific knowledge about accelerations and decelerations demands during soccer training.
- Characterize accelerations and decelerations in soccer training without applying a minimum effort duration.
- Provide a new method to classify accelerations and decelerations intensities during soccer training, by adapting the previous published individual percentage intensity method.
- With the individualize and relative intensity approach, compare accelerations and decelerations demands of different exercise' categories of goalkeeper training.
- With the individualize and relative intensity approach, compare accelerations and decelerations demands of different soccer activities (training drills and matches).
- With the individualize and relative intensity approach, compare accelerations and decelerations demands of different warm-up' strategies during soccer training.
- Compare peak efforts (maximal speeds, maximal accelerations, and maximal decelerations) of young players during competition and during field tests (maximal speed and maximal acceleration) according to different age groups.
- Analyze how soccer players reach the most commonly used sprint threshold (> 25.2 $km{\cdot}h^{-1}$) and what that fixed threshold represents to each player regarding their individual maximal capacities registered during competition.
- Characterize match peak speeds, by analyzing how soccer players reach and leave those efforts, during a 20 second time window (10 seconds immediately before and 10 seconds immediately after the match peak speed).
- Compare peak accelerations and decelerations occurred during the pro-agility test, during matches, and during training sessions.

These eleven specific objectives were developed as eleven scientific papers, which are presented in this thesis.

2.2. Thesis Organization

This thesis is organized in seven chapters: Introduction, Objectives, Methods, Scientific Research (divided in two subchapters: Systematic Reviews and Empirical Studies), General Discussion, Conclusions and References. The first chapter, Introduction, contextualizes the current knowledge and the potential challenges regarding the monitoring process of accelerations and decelerations imposed in soccer players. The Objectives chapter describes the main and specific objectives, presenting how they were organized across this thesis. The Methods chapter describes briefly the different experimental approaches across this season. The Scientific Research presents the eleven scientific studies developed during this thesis, diving them in two main categories: systematic reviews and empirical studies. The General Discussion discusses the findings reported in this thesis, presenting limitations, potential future directions for research, and practical applications. The Conclusions chapter summarizes the main findings of all the research conducted during this thesis. Finally, the References chapter assembles all references cited across this document.

Scientific studies are presented according to the respective sub-chapter as displayed in Figure 1. Additionally, papers status is referenced in Table 1.

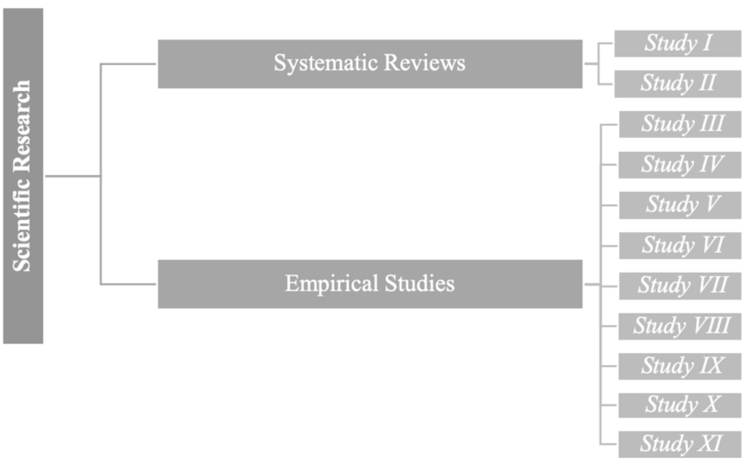

Figure 1. Schematic organization of the scientific studies

Table 1. Scientific studies information

Study	Title	Citation
I	Training Load Within a Soccer Microcycle Week – A Systematic Review	Silva H, Nakamura FY, Castellano J, Marcelino R. Training Load Within a Soccer Microcycle Week—A Systematic Review. Strength & Conditioning Journal. 2022 Mar 16:10-519. DOI: 10.1519/SSC.0000000000000765
II	Acceleration and deceleration demands during training sessions in soccer: a systematic review	Silva H, Nakamura FY, Beato M, Marcelino R. Acceleration and deceleration demands during training sessions in football: a systematic review. Science and Medicine in Football. Jun 26:1-16. DOI: 10.1080/24733938.2022.2090600
III	Using minimum effort duration can compromise the analysis of acceleration and deceleration demands in soccer	Silva H, Nakamura FY, Ribeiro J, Asian-Clemente J, Roriz P, Marcelino R. Using minimum effort duration can compromise the analysis of acceleration and deceleration demands in football. International Journal of Performance Analysis in Sport. 2023 Apr 14:1-3. DOI: 10.1080/24748668.2023.2201745
IV	Adapting the percentage intensity method to assess accelerations and decelerations in soccer training: moving beyond absolute and arbitrary thresholds	Silva H, Nakamura F, Serpiello F, Ribeiro J, Roriz P, Marcelino R. Adapting the percentage intensity method to assess accelerations and decelerations in football training: moving beyond absolute and arbitrary thresholds. (PrePrint). DOI: 10.51224/SRXIV.286
V	Goalkeeper horizontal accelerations and decelerations during soccer training: varying exercises could be the best option	Silva H, Nakamura FY, Bajanca C, Otte F, Pinho G, Moreno-Pérez V, Marcelino R. Goalkeeper horizontal accelerations and decelerations during soccer training: varying exercises could be the best option
VI	Acceleration and deceleration demands of different soccer drills	Silva H, Nakamura FY, Bajanca C, Pinho, Serpiello FR, Marcelino R. Acceleration and deceleration demands during different football activities
VII	The impact of different warm-up strategies on acceleration and deceleration demands in highly-trained soccer players	Silva H, Nakamura FY, Bajanca C, Pinho, G, Loturco I, Marcelino R. The impact of different warm-up strategies on acceleration and deceleration demands in highly-trained soccer players
VIII	Match peak speeds, and maximum accelerations and decelerations differ in young football players: expression of maximal capacities is dependent of match context.	Silva H, Nakamura FY, Casamichana D, Barba E, Castellano J, Marcelino, R. Match peak speeds, and maximum accelerations and decelerations differ in young football players: expression of maximal capacities is dependent of match context
IX	The path to sprinting: how soccer players sprint and what does the 25.2 km·h^{-1} threshold represent	Silva H, Nakamura FY, Mendez-Villanueva A, Gómez-Diaz A, Menezes P, Marcelino, R. The path to sprinting: how soccer players sprint and what does the 25.2 km·h^{-1} threshold represent
X	Peak match sprinting speed during soccer matches: analyzing the pre- and post- peak speed dynamics	Silva H, Nakamura FY, Racil G, Gómez-Diaz A, Menezes P, Chamari K, Marcelino, R. Peak match sprinting speed during soccer matches: analyzing the pre- and post- peak speed dynamics

XI	Does the pro-agility test and training sessions mimic soccer matches peak accelerations and decelerations?	Silva H, Nakamura FY, Roriz P, Marcelino, R. Does the pro-agility test and training sessions mimic soccer matches peak accelerations and decelerations?

Finally, two notes should be referred. First, regarding references, since several studies were developed during this thesis, and all relate to one topic (accelerations and decelerations), references are presented at the end of this thesis, combining all sections of this thesis. With this, reference duplicates are avoided across this document. Secondly, scientific studies were published/submitted at different scientific journals, with different submission guidelines. As so, to highlight a practical view of each scientific study, a practical application section was added to all studies that have a final version without it.

CHAPTER III: METHODS

This chapter briefly presents the methodology used during this thesis construction. Since eleven scientific papers were produced, specific details of each study can be found in the respective study Methods section (chapter IV: Scientific Research).

3.1. Sample

Characterization of the population investigated during this thesis is presented in Table 2. However, since the sample of studies I and II – systematic reviews – were not selected to study, but rather filtered according to inclusion and exclusion criteria, a brief characterization is presented separately. Both reviews included players from different countries and different competitions, as no specific exclusion criteria was previously stipulated before conducting the reviews. Regarding players' levels, one study (44) has proposed the following classification: Tier 0: Sedentary; Tier 1: Recreationally Active; Tier 2: Trained/Developmental; Tier 3: Highly Trained/National Level; Tier 4: Elite/International Level; or Tier 5: World Class. Levels 2, 3 and 4 were included in both systematic reviews, which, coincidentally, had the same average age interval (16-28 years old). Study I included only male players, while study II included male and female players, but a clear majority of male soccer players (93%).

Regarding empirical research, all subjects were male, and except for study VIII (that incorporated young players [even if playing in Spanish top divisions of their age group]), all studies incorporated high level players (Tiers 3, 4 and 5). Additional information is presented in Table 2 and at each respective study.

Table 2. Sample characteristics for each study

Study	Country	Competition	Level tier	Players (*n*)	Playing Positions	Mean age
III	Portugal	First division	3, 4	42	CD, FB, CM, WM, FW	26.7±4.2
IV	Portugal	First division	3, 4	42	CD, FB, CM, WM, FW	26.7±4.2
V	Portugal	U23 League	3	3	GK	18.3±1.5
VI	Portugal	U23 League	3	19	CD, FB, CM, WM, FW	20.1±1.2
VII	Portugal	U23 League	3	19	CD, FB, CM, WM, FW	20.1±1.2
VIII	Spain	Youth first divisions	2, 3	78	CD, FB, CM, WM, FW	14.9±0.4 – 19.4±2.5
IX	Brazil	First division	5	20	CD, FB, CM, WM, FW	27.8±5.3
X	Brazil	First division	5	20	CD, FB, CM, WM, FW	27.8±5.3
XI	Portugal	First division	3	17	Not separated	27.5 ± 5.2

Note: The Participant Classification Framework tiers (Tier 0: Sedentary; Tier 1: Recreationally Active; Tier 2: Trained/Developmental; Tier 3: Highly Trained/National Level; Tier 4: Elite/International Level; or Tier 5: World Class.). GK = Goalkeepers; CD = Central Defenders; FB = Fullbacks; CM = Central Midfielders; WM = Wide Midfielders; FW = Forwards.

3.2. Equipment

With the exception of studies I and II (systematic reviews), GPS equipment was used during all scientific studies. Brands and models used were Catapult Vector S7 (studies III-VII and XI) and Vector X7 (studies III, IV) (Catapult Sports, Melbourne, Australia) and WIMU PRO (studies VIII-X) (Realtrack Systems SL, Almeria, Spain), with 10 Hz as sampling frequency. Of note, the studies III and IV included two different teams that used two different models of the same manufacturer. However, comparisons between teams were also conducted, illustrating the same result, regardless of the specific model. All systems are FIFA certified and the 10 Hz sampling frequency has been validated for velocity assessments (45,46) Additionally, in study VIII, Photocells WITTY (Microgate, Italy) were used to assess time, during acceleration and sprint tests.

3.3. Procedures

Data was collected from different teams during different time periods. Specifically, one month was selected to analysis when treating raw data because this time period generated millions of datapoints and a longer period could potentially compromise the data treatment and subsequent analysis. Furthermore, by considering different microcycles, the one-month period account for the influence of context (match or training sessions) on overall load (47), while providing an insight of the real scenario of players activities. However, if datasets were retrieved as absolute data (i.e., peak values), the larger periods possible were selected: half a season for study XI, and a full season for study VI. A summary of time periods, and number of training sessions or matches is presented in Table 3.

Table 3. Time periods, and number of training sessions or matches from which data sets were collected.

Study	Time period	Training sessions (*n*)	Matches (*n*)
III	1 month	38	0
IV	1 month	38	0
V	1 month	19	0
VI	1 month	19	4
VII	1 month	19	0

VIII	1 year	0	84
IX	1 month	0	6
X	1 month	0	6
XI	5 months	85	17

3.3.1. External load[5] monitoring

During each training session or match, players used GPS equipment to monitor their external load. Utilization of devices followed manufacturers' instructions, being secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use. Data was then collected from each individual equipment using specific brand software. If working data were to be raw data, selected files were collected after players identification has been removed and codified. This raw data was collected before data was "treated" by the equipment software with developed filters. If working data were to be previously treated (studies VIII and XI), the same procedure was to be taken but just after data was "treated" by the equipment software.

Importantly, teams performed all activities as planned, without any interference of research purposes. That is, no request was address to any player, coach, team, or club, that would cause any change of their standard procedures.

3.3.2. Testing Procedures

Field tests were conducted during two studies (VI and XI). In study VI, maximal speed (0-30 meters) and maximal acceleration (0-5 meters) were assessed. Photocells WITTY (Microgate, Italy) were placed at 0, 5 and 30 meters (Figure 2). The timer started and stopped counting when the player crossed between the start and finish photocells respectively. Players were instructed to give their absolute maximum effort during the test's performances.

[5] When monitoring players activities, practitioners can assess the Internal Load and/or the External Load. While the Internal Load refers to the physiological responses of the players to a specific activity or stimulus, the External Load refers to the amount of work performed by the players. For example, assessing the average heart rate of one match would show how players responded to the match. On the other hand, assessing the number of accelerations and decelerations performed during one match, would show the amount of work (as number of these efforts) produced during the match.

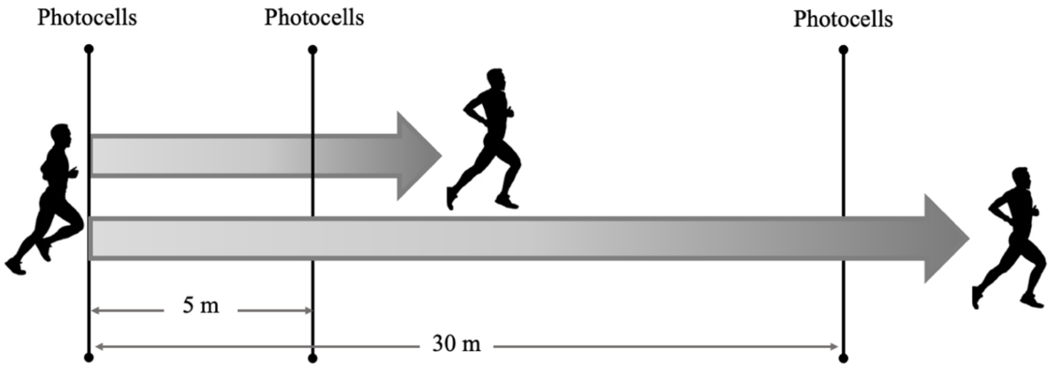

Figure 2. Maximal speed (0-30 meters) and maximal acceleration (0-5 meters) field tests

In study XI, a change of direction speed test was applied: the pro-agility test (5-10-5). Players were instructed start upright and quickly change their direction to both turning lines, place at 5 meters each from the starting line (Figure 3). Maximal accelerations and decelerations were assessed with GPS.

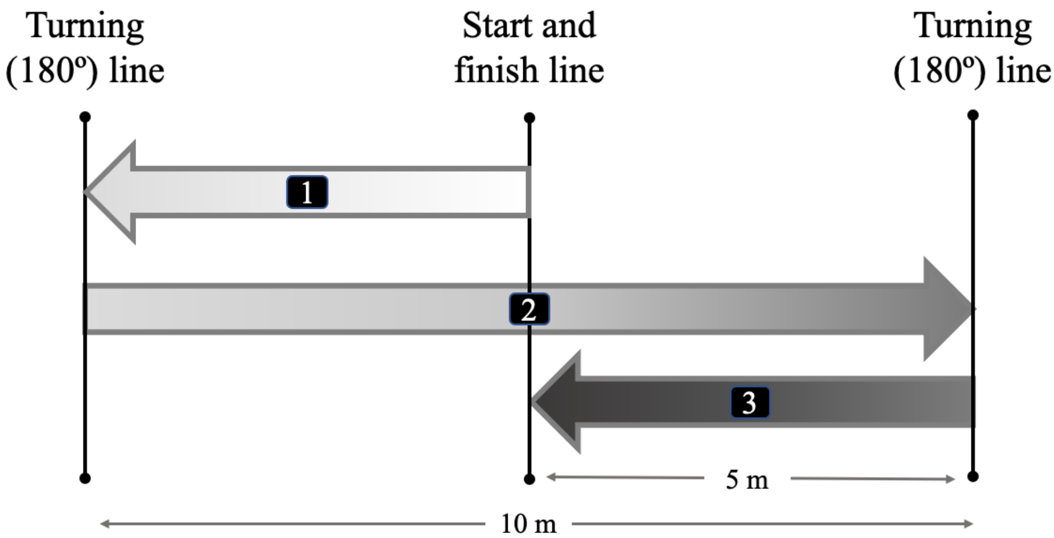

Figure 3. Pro-agility (5-10-5) test

3.4. Ethical Considerations

Each club obtained permissions from players or parents (when sample was under 18 years old) to collect and present data for scientific research purposes. Since players wore GPS tracking devices as required for training and match routine monitoring, Ethics

Committee clearance was not required (48). Nevertheless, research was approved by the Ethic Committee of the University of Maia (35/2021) and was conducted following the guidelines of the Declaration of Helsinki.

3.5. Statistical Analysis

Both systematic reviews (studies I and II) were conducted according to PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis) guidelines (49). These guidelines aim to improve the quality and facilitate the understanding of reviews, by establishing a protocol to be followed. Within this protocol, appear topics such as the identification of eligibility criteria, description of the selection process, and the assessment of the risk of bias in individual studies. To assess the risk of bias, the Risk Of Bias In Non-Randomized Studies of Interventions tool (ROBINS-I) (50) was implemented. ROBINS-I is a screening tool with different domains: Bias due to confounding; Bias due to selection of participants; Bias in classification of interventions; Bias due to deviations from intended interventions; Bias due to missing data; Bias in measurement of outcomes; Bias in selection of the reported result; and Overall risk of bias. These domains result in a classification of low, moderate, serious, or crucial risk of bias. Additionally, since study II included different measurement methods, a Z-score analysis was used to allow comparisons between different measurement methods. By accounting for the average value of the measurement and the standard deviation (variability), the *Z*-scores provides a practical comparison between different variables (51).

In study III, one-way analysis of variance (ANOVA) was performed to assess differences between playing positions in the study selected variables (percentage of occurrences, initial velocities and acceleration and deceleration magnitude), providing information if the difference among groups exceeds the expected difference for a chance model (52). Additionally, means differences were calculated with Tukey post-hoc test, allowing the identification of the registered differences.

In study IV, linear regressions and Pearson correlation (r) were calculated to analyze the relationship between the maximal acceleration and decelerations and starting speeds. Linear regression quantifies the nature of the relationship between variables (how much the variable B will change when the variable A changes by a certain amount), and correlation assesses the strength between two variables (measures the extent to which numeric variables are associated with one another, ranging from –1 to +1) (52). Additionally, mean paired differences compared accelerations and decelerations magnitudes between subsequent starting speed intervals. This method was applied to compare different variables (accelerations and decelerations) performed by the same individual – that is, each player was compared with his own performances (53). Effect size of mean paired differences were established with Cohen's (*d*) and as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (CI) (54). The 90% CI has been suggested for two main reasons: it implies that "an outcome is clear if the true value is very unlikely to be substantial in a positive and/or negative sense", and it also discourages interpretation the outcome as significant or non-significant (5% level) (54). Additionally, if the CI crossed zero, an unclear effect size was established (55).

Mean paired differences were also conducted in studies V-VII, X and XI. During study VIII, independent mean differences were estimated instead of paired mean differences because comparisons were conducted at players according to their age group and not within players. Regarding players, differences between their positions were also analyzed with independent groups contrasts in studies VI, VIII and IX.

CHAPTER IV: SCIENTIFIC RESEARCH

CHAPTER IV: SCIENTIFIC RESEARCH

SUBCHAPTER: SYSTEMATIC REVIEWS

4.1. Study I (Training Load Within a Soccer Microcycle Week—A Systematic Review)

Citation: Silva H, Nakamura FY, Castellano J, Marcelino R. Training Load Within a Soccer Microcycle Week—A Systematic Review. Strength & Conditioning Journal. 2022 Mar 16:10-519. DOI: 10.1519/SSC.0000000000000765

Abstract

Quantifying training load is important to assure that athletes are correctly responding to training prescription, and to reduce injury risk. Training load can be divided in internal training load, the response of an individual to the training demands, using variables such as Rating of Perceived Exertion (RPE) or heart rate variables; and external training load, the physical "work" of the players, like total distance or accelerations. In this review, we aimed to analyze training load (internal and external) during a training week (microcycle) in soccer players. Systematic searches of three electronic databases (PubMed, SPORTDiscus, Web of Science) were conducted, and PRISMA guidelines were followed. From 1718 studies initially found, 16 were selected to this review after screening. Descriptive and Z-score analysis were performed for each variable. Sample of this review was 317 male soccer players with average ages ranging from 13.0 to 27.6 years, competing in elite, professional and youth levels. Different training load measurements methods were used: acceleration and deceleration, average speed, high-speed running, sprint, total distance, player load, %HRmax and RPE. MD-3 was the most demanding session of the week, with the exception of deceleration, average speed and player load demands. MD-1 was the least demanding session of the week for almost all metrics, except for sprint and RPE. In conclusion, middle of the week sessions appear to be chosen to apply higher training loads, while training sessions immediately before and after the match can be used to taper or recover.

Keywords: recovery, workload, periodization, physiological demands

Introduction

Training load has been defined as the amount of stress placed from a single or multiple training sessions over a period of time to an individual (56) and is often used to evaluate if players are meeting training requirements, if the training is providing the desired stimuli in accordance to the player's capabilities (57,58) and to prevent excessive amounts of training that can increase injury risk (59). Training load can be divided as External Training Load, the work completed by the athlete (58), and Internal Training Load, the psychophysiological responses of the athlete to the exercise demands (60).

Measurement methods can be simple and with no equipment requirement such as Rate of Perceived Exertion (RPE) (61–63) or more complex and equipment dependent as the measure of heart rate. Different methods can also have relationships with each other. For example, players' heart rate variables, as heart rate reserve, are frequently used due to their high relationship with oxygen uptake (VO_2) (64,65). Interestingly, internal (Bannister's TRIMP [heart rate training impulse], Edwards TRIMP [summated heart rate zones] and s-RPE) and external load (total distance covered, low-speed activity [<14.4 km/h], high-speed running [>14.4 km/h], very high-speed running [>19.8 km/h] and Player Load [accumulated accelerations]) showed moderate to large correlations with each other (57).

The importance of both external and internal training load measurements in the training process has been highlighted in the literature. For example, one study found increased injury risk when players experienced high weekly cumulative loads, or large weekly changes (66). Moreover, monitoring training load can also help to understand the reasons for changes in performance as in preventing excessive fatigue (58).

Despite this recognized importance, practical implementation of monitoring tools may vary. For example, the lack of access to equipment may lead practitioners to focus their measure on RPE. In professional clubs, training load quantification may be implemented with other methods. For instance, Akenhead et al. (3) surveyed 82 soccer coaches from professional clubs about the most used variables to quantify training load. The authors found that acceleration measurements (peak acceleration, velocity change load and accelerations occurred above a specific threshold) were the most used variable to quantify training load during training practices. Interestingly, accelerations were found to be moderately predictable of the RPE training load (67). Because RPE is a subjective measurement, with each player registering his own training load perception, training load may be perceived differently by players and coaches, with players perceiving training sessions with higher intensity than what is intended by coaches (68). As so, the transfer from this training load knowledge to practice application is of high importance, with special reference to development of players' physiological capacities.

In soccer training, coaches often use a weekly structured organization, called microcycle, that manipulates players' conditioning and recovery status (69). In this organization, tactical periodization is often used and divides the week in recovery sessions, that usually occur before and after the game, and acquisition days, normally placed in the middle of the week (70). In this approach, tactical, technical, physiological, and psychological elements are stimulated together (71) in acquisition sessions, which are expected to elicit a higher training load than the recovery sessions (72). In acquisition days, each of the three physical capacities, strength, endurance, and speed, are differently stimulated. As so, if one given capacity is maximally elicited in one training session, the other capacities recover (73). To identify training sessions in the microcycle, the "match day minus" format has been used (26,69). This format identifies training sessions according to the distance to the match day (MD), with MD-1 referring to one day before the match, MD-2 referring to two days before the match and so on (74), and training load tends to decrease as MD approaches with the middle of the week eliciting higher demands to soccer players, and MD-1 the lowest (64,75,76). However, this can change with recovery and compensatory sessions. For example, one study (69) found higher accelerations and decelerations demands in the compensatory session than any other training session but this trend was not observed in the other training load measurements (total distance, high-speed running and sprint). In the same study, forward players performed less accelerations and decelerations efforts, and distance ran in sprints and high-speed running was shorter in compensatory sessions. This strategy is used because participation time in matches determines players' weekly training load accumulation, which results in a differentiation of three groups of players (match participation times of: ≥45 min, <45 min, and 0 min) (77). As so, monitoring training load is fundamental to ensure a proper recovery and the best preparedness state with competition in mind.

A particularity in this topic is the difference selection of measurement methods and variables in both research and practice fields. Moreover, within each method, different intensity thresholds can be presented. When classifying high intensity accelerations, both 3m/s^2 (78,79) and 4 m/s^2 (21,80) thresholds have been used. Similarly, sprinting category was used with running speed >24.0 km/h (81,82) or >25.2 km/h thresholds (83,84). As so, it will also be interesting to allow an interpretation that considers this.

Therefore, the aim of this review is to present a comprehensive analysis about internal and external training load across a soccer microcycle, considering methods of assessment. This approach could help coaches and practitioners to better use and interpret the extensive training load data when preparing and analyzing the training week.

Methods

Experimental Approach to the Problem

The current review operationalization was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis) guidelines (49).

Systematic searches of three electronic databases (PubMed, SPORTDiscus, Web of Science) were conducted to identify peer-reviewed articles published in the English language between January 2000 and October 2020.

Literature Search

Search terms in each electronic database were “football” OR “soccer” AND “training load” OR “external load” OR “internal load” AND “week” OR “periodization” OR “microcycle” OR “plan*” OR “sessions” OR “interday” OR “schedule”. Additional filters were created to select only peer-reviewed articles in English and post-January 2000.

Inclusion Criteria

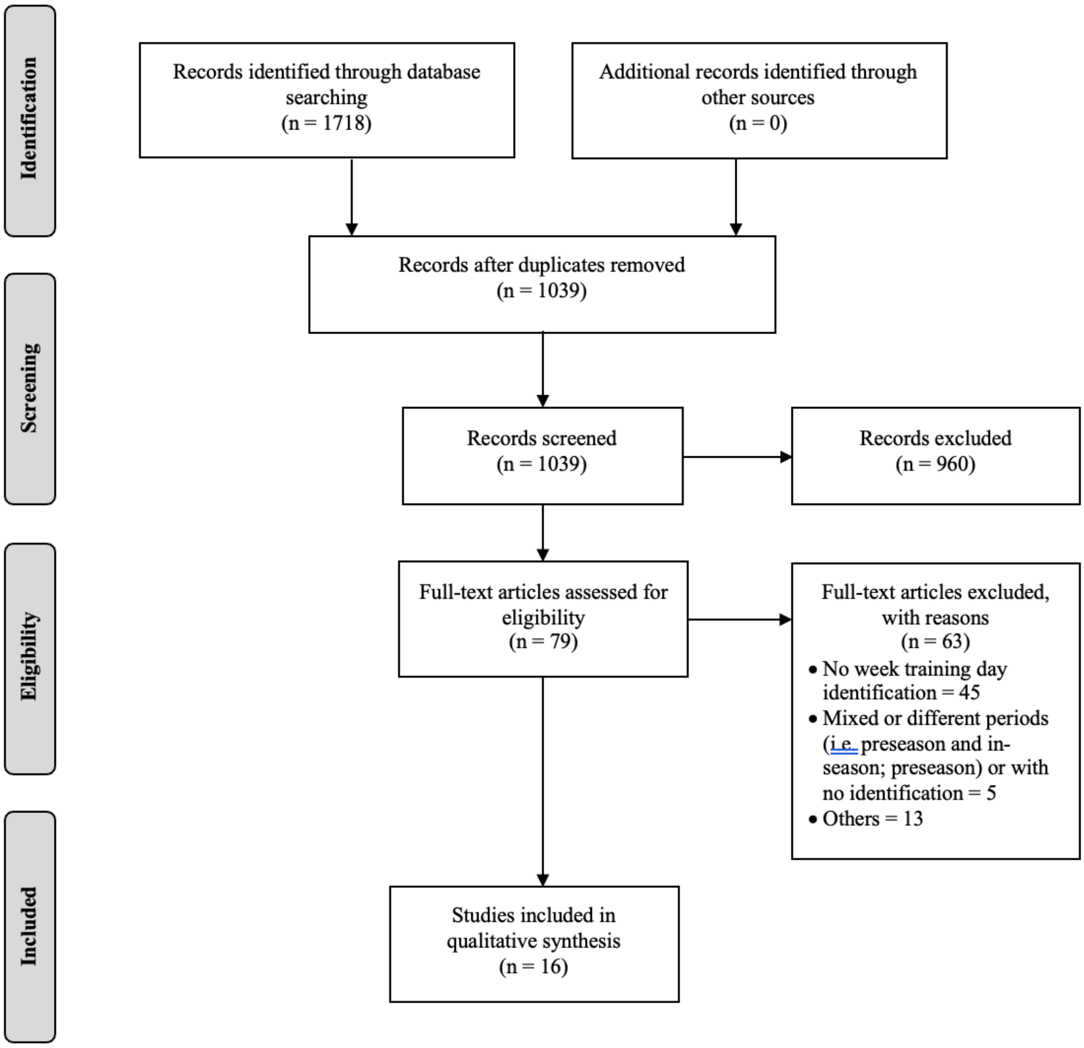

Figure 4. PRISMA flow diagram

Studies were eligible for further analysis if the following inclusion criteria were met: a) original research articles; b) team soccer; c) able soccer player; d) full week training sessions; e) training sessions identifiable in relation to match day; f) in-season; g) internal and/or external training load clearly described. Inquiries, as Hooper Index, were excluded from this review. As Impellizzeri et al. (60) stated, these measurements should not be considered internal load indicators because they represent a measure of post exercise response to the internal load. Or, as recently proposed, this type of measurements, that evaluate the effects caused by training session(s), could be classified as training effects instead of training load (85). Exclusion criteria can be found in supplementary information (Table S1). Furthermore, we did not extrapolate/calculate variables from data. For example, even if RPE and duration were reported, we did not calculate the session RPE.

Studies titles and abstracts were screened and studies with clear exclusion criteria were excluded. Afterwards, selected studies were screened fully and those that exhibit any exclusion criteria were excluded. A flow chart of the search strategy and study selection is shown in Figure 4.

Statistical analysis

A descriptive analysis is presented. Absolute values from the selected studies were used to compare differences between match-day and between training sessions during the microcycle.

Training load variables that were present in only one study and, therefore, did not allow comparison with other data, were excluded. These variables refer to: average distance, dynamic stress load, equivalent distance, high metabolic load, impacts, low-moderate running, max speed, pace, Polar Training Load (a metrically scaled, predefined variable of the Polar Team Pro Software, which includes the session's duration and heart rate data, player's training history, a sport specific factor as well as the player's aerobic capacity (86)) and TRIMPmod (modified training impulse calculated from the raw data and represents the time spent in certain heart rate zones multiplied by a weighting factor (86)). Since different speed categories and scales were used, only data from HSR and sprint were included. Finally, different terms were used for classifying high intensity running (HSR, high-speed and high-intensity), and therefore combined in one category: HSR.

Z-score analysis was used to allow comparisons between different measurement methods and was calculated for each variable. If one variable or training day was used only in one study, that data was excluded from Z-Score. However, this information is available in the supplementary information. Z-Score analysis was presented in forest plots (Figure 6) using GraphPad Prism version 9.2.0 for macOS, GraphPad Software, San Diego, California USA. Since MD+1 session was approached differently by teams (as compensation, recovery or with no identification) we decided to not present it as their visual presentation could mislead conclusions. Additionally, MD-6 was also excluded because it had only one variable analyzed.

Results

Studies Selected

The search strategy yielded 1718 studies. After removing duplicates, a total of 1039 studies were selected for title and abstract screening, excluding 960 papers. Seventy-nine studies were fully screened, resulting in 16 studies included in this review. The major exclusion criterion of full screening was the lack of week training day identification (Figure 4).

Risk of Bias

The risk of bias assessment followed Cochrane recommendations and used the Risk Of Bias In Non-Randomized Studies of Interventions tool (ROBINS-I) (50). This tool uses different domains that results in a classification of low, moderate, serious or crucial risk of bias for each domain and an overall assessment of each study. Domains of ROBINS-I are: 1) Bias due to confounding; 2) Bias due to selection of participants; 3) Bias in classification of interventions; 4) Bias due to deviations from intended interventions; 5) Bias due to missing data; 6) Bias in measurement of outcomes; 7) Bias in selection of the reported result. Finally, an Overall risk of bias is provided. To perform this assessment, each study was analyzed by two authors, with a third solving discordances, following the guidelines from the detailed guidance (87).

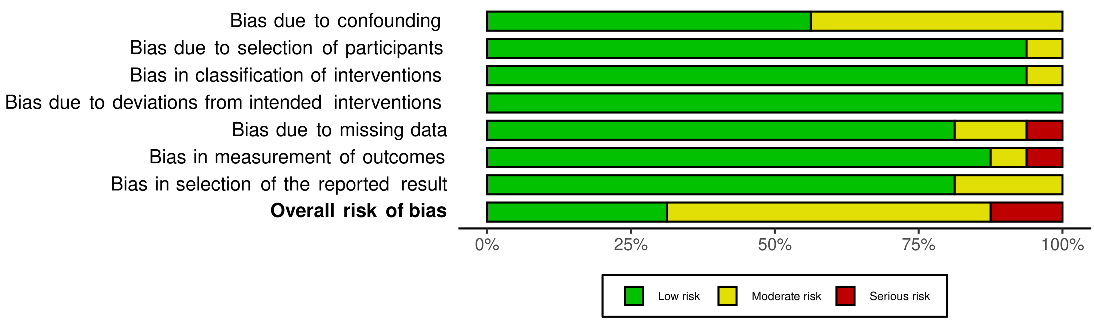

Figure 5. Summary plot of the risk of bias for each seven domains and the overall risk of bias ROBINS-I tool.

A summary plot, with each domain and the overall risk of bias assessment is presented (Figure 5). To do so, we used Risk-of-bias VISualization (robvis) (88).

Sample Characteristics

All subjects (*n*= 317 in total) are male with ages ranging from 13.0 to 27.6 years. Competition levels are elite (74,75,89–95), professional (26,30,69,76,86,96–101) and young (102,103). Training load was analyzed with external load (30,69,89,98,100,101) or internal load (95–97,103) separately, or with both internal and external load measurements (26,74–76,86,90–94,99,102). Weeks varied between 2 to 7 training sessions, and 1 to 3 matches per week.

Microcycle Training Load

External Training Load

Acceleration and Deceleration (ACC & DEC)

Acceleration (ACC) and deceleration (DEC) measurements were presented in 8 studies (26,30,69,86,94,98–100) and training demands were registered as the sum and relative sum of ACC and DEC (98), number of ACC and DEC (30,69,86,94,99), number of ACC (100) and distance covered in ACC and DEC (26). Match day (MD) demands was not the focus of this review, but since 5 studies included comparisons between match and training demands we decided to present that data. As so, MD had the highest values of the week for ACC and DEC (76,86,98,100). One exception was found in goalkeeper (GK) training with MD eliciting fewer demands than any training session (30). In training, higher demands were registered in MD-3 (86,98) and MD-4 (26,30,99,100) sessions, and lowest demands were found in MD-2 (98) and MD-1 (26,30,69,86,99,100). One study (94) divided ACC and DEC according to different thresholds, and MD-4 placed higher ACC and DEC between 2 and 4m/s^2, while lower demands were found in MD-1 session. Accordingly, ACC and DEC >4m/s^2 were higher in MD-4 and MD-3 sessions, and lower in MD-5. Finally, one paper (69) measured training load from a compensatory training session (MD+1C), that had the objective of replicating match loads to players with <60 min of competition, and a recovery training session (MD+1C) to the other players. This is important to highlight because MD+1C presented the highest ACC and DEC demands of the week in this study.

Average speed

This training load method is measured in meters per min, and was registered in 5 studies (90–93,101). Higher average speed demands were found in MD-2 (93), MD-3 (90), MD-5 (101), MD+1 (91,92); while lower demands were elicited in MD-1 (91–93,101) and MD-4 (90) sessions.

High-Speed Running (HSR)

This measurement method comprises high-speed running (HSR), high intensity running and high-speed nomenclatures. Eleven studies (26,69,86,90–93,98–100,102) reported training demands in HSR, using different measurements as average HSR (m/min) (98), HSR distance (26,69,86,90–93,99,100,102) and HSR efforts (26). MD demands were higher than any other training session (86,98,100,102), and MD-1 (102), MD-3 (86,93,98,99), MD-4 (26,69,90) and MD-5 (92,100) were the most demanding training session of the week. Conversely, MD-1 (26,69,86,90,92,93,98–100) and MD+1 (102) training sessions elicited lower HSR demands. One study (91) found different results in training sessions demands according to the match result (win, draw or defeat) following that week, with higher demands found in MD-4 before wins, MD-5 before draws and MD-3 before defeats. Regarding the least demanding training session, results were divided between MD-1 (before wins and defeats) and MD+1 (before draws). Other authors (92) compare HSR demands in one, two and three-games per week and found higher demands in MD regardless of the week organization. Higher and lower demands were found in MD-3 and MD-1 sessions respectively with one-game per week. Two-games per week differ in the lower demanding session, being MD-4, but that can be justified by the proximity to the previous game (2 days after the previous match, with no training session the day before). Three-games per week was not analyzed because it had only one training session between matches.

Player Load

Player Load is a training load indicator that combines accelerations produced in three planes of body movement and is measured with a triaxial accelerometer (12). Player Load was reported in 3 studies (26,100,101) and when MD load was reported (100), the highest demands of the microcycle was placed in that day. When comparing training sessions, MD-5 (100,101) and MD-4 (26) presented the highest values of the week, while MD-1 (26,100,101) presented the lowest.

Sprint

Sprint loads were measured in 8 studies (26,69,86,89,93,98,99,101), and presented as relative sprints (m/min) and relative sprints distance (98), distance (26,69,86,89,93,99,101) and efforts (number) (26). When registered, sprint demands were higher in MD (86,89,98) than MD-3 (86,89,98,99), MD-4 (26,69) and MD-5 (101), the highest training sessions of the week. MD-3 also had the highest sprint demands for central defenders, but full-backs, center midfielders, wide forwards and forwards, performed more distance when sprinting in MD-2 (93). Conversely, MD-1 (26,69,86,93), MD+2 (101) and MD-4 (89) were the least demanding sessions. Two studies presented equal lower sprint demands (means) in two different training sessions: Owen et al. (98) identified those sessions as MD-1 and MD-2, while in Rey et al. study (99), MD-6 and MD-1 were the least demanding sessions of the microcycle. As in HSR category, the study that analyzed different number of games per week, also measured sprints (89). MD placed the highest demand of the week, followed by MD-3 in one and two-game weeks. In both week-types, the authors did not report any distance covered sprinting in MD-4, a training session that was placed as the first training session after the match.

Finally, we must highlight 2 studies. First, we considered one study using this parameter that classified sprints as efforts >20km/h (101). We respected the authors' classification in this section. However, since these thresholds are different from others presented in this review, when analyzing z-scores, we changed this study sprint reports to HSR. And second, one study (94) measured the distance covered above 6.6 m/s with no classification of intensity. Since this threshold (23.8 km/h) is usually used in sprint category, we added these study findings to this label. In this study, MD-3 and MD-5 place the highest and lowest demands respectively. As so, we can consider that the total number of studies that included sprints were 9.

Total Distance

Total distance was the external load variable more frequent in this review, with 13 studies (26,30,69,86,90–94,98–101) measuring it. Findings were reported with relative distance (94,98) and total distance covered (26,30,69,86,90–93,99–101). When considered, MD was the most demanding session of the week (30,86,98,100). Regarding training sessions exclusively, MD-5 (91,92,94,100,101), MD-4 (26,30,90,99) and MD-3 (69,86,93,94,98) elicited higher demands, while MD-1 (26,69,86,90–94,98–101) and MD+1 (30) elicited lower.

Internal Training Load

Percentage of maximal Heart Rate (%HRmax)

Heart rate variables were monitored in 3 papers (26,90,99) as a percentage of maximal heart rate (%HRmax). In these studies, the authors reported a percentage of the maximal heart rate (90,99) and time spent above 90% of the maximal heart rate (26). Higher demands were found in MD-4 (99) and MD-3 (90) and lower demands in MD-1 (26,99) training sessions. Malone et al. (90) presented the same mean percentage of maximal heart rate in both MD-2 and MD-1. Similarly, Akenhead et al. (26) reported the same mean for time spent above 90% of maximal heart rate for MD-5 and MD-4, the most demanding sessions.

Rating of Perceived Exertion (RPE)

Eight studies (90–94,96,99,102) analyzed demands in two formats: RPE, the reported individual perceived exertion using a specific scale (90,94,99); and session-RPE (s-RPE), that multiplied RPE with training duration to calculate session load (91–94,96,102). Within this last method, two studies divided s-RPE in s-RPE muscular, reporting perceived exertion for musculature efforts and s-RPE respiratory for respiratory efforts (96). Higher perceived demands were reported in MD-4 (99) and MD-3 (90,92–

94,96,102), and lower demands were found in MD-1 (93,94,96,99) and MD+1 (91,92,102). Malone et al. (90) reported the lower RPE values in 3 training sessions, MD-4, MD-2 and MD-1. Moreover, a different approach was used by comparing results from the match following the training week, and higher demands were reported in MD-4 for draws, MD-3 for wins and both MD-4 and MD-3 for defeats (91). Differences between starters and non-starters in MD demands were also found, with this day being the most demanding for starters and the least demanding day for non-starters (96). MD was also the most demanding day of the week in one study (102).

Z-Score analysis results

In this analysis, we have separated ACC and DEC, and as so, the values of one study that used sum of ACC and DEC (98) were excluded for this analysis. Additionally, since the purpose of this review was to analyze training load demands during training sessions, MD demands were excluded.

Higher demands were found in MD-3 session for ACC (0.89 ± 0.46), HSR (0.94 ± 0.50), sprint (1.08 ± 0.79), total distance (0.95 ± 0.27), percentage of maximal heart rate (0.77 ± 0.88), and RPE (1.04 ± 0.23). Additionally, MD-4 elicited more demands in DEC (0.95 ± 0.36), MD+1 regarding average speed (1.11 ± 0.67) and MD-5 in player load (0.93 ± 0.70). Conversely, lower demands were found in MD-1 for all measurement methods except sprint and RPE. As so, MD-1 was the least demanding session of the week for ACC (-0.77 ± 0.54), DEC (-0.978 ± 0.27), average speed (-1.04 ± 0.24), HSR (-0.89 ± 0.44), total distance (-1.30 ± 0.31), player load (-1.12 ± 0.07) and percentage of maximal heart rate (-1.08 ± 0.34). Sprint had fewer demands in MD-5 than other session of the week (-0.65 ± 0.18) and MD+1 was the least demanding session in terms of RPE method (-3.61 ± 141). Z-Scores for all variables are presented in Table 4. Z-Scores are also presented in Figure 6 except for MD-6 and MD+1, as explained in methods section.

Table 4. Z-Score values (presented as mean ± standard deviation) for all measurement methods.

	MD-6	MD-5	MD-4	MD-3	MD-2	MD-1	MD+1	MD+1C	MD+1R
ACC	-	-0.76 ± 0.65	0.81 ± 0.41	0.89 ± 0.46	-0.39 ± 0.54	-0.77 ± 0.54	-	-	-
DEC	-	-0.90 ± 0.14	0.95 ± 0.37	0.83 ± 0.51	-0.27 ± 0.44	-0.98 ± 0.27	-	-	-
Average Speed	-	0.18 ± 0.93	-0.23 ± 0.52	-0.26 ± 0.54	0.28 ± 0.98	-1.05 ± 0.24	1.11 ± 0.68	-	-
HSR	-	0.82 ± 1.12	0.37 ± 0.71	0.94 ± 0.50	-0.04 ± 0.43	-0.89 ± 0.44	-0.83 ± 0.37	-0.64 ± 0.19	-0.76 ± 0.40
Sprint	-	-0.65 ± 0.18	0.03 ± 0.90	1.08 ± 0.79	-0.09 ± 0.48	-0.63 ± 0.57	-	-	-
Total Distance	-	0.69 ± 0.90	0.57 ± 0.41	0.95 ± 0.27	-0.05 ± 0.40	-1.30 ± 0.31	-0.62 ± 0.27	-0.03 ± 0.70	-0.66 ± 0.07
Player Load	-	0.93 ± 0.70	0.26 ± 0.61	-	-0.04 ± 0.61	-1.12 ± 0.07	-	-	-
%HRmax	-	-	0.61 ± 0.48	0.77 ± 0.88	-0.33 ± 0.59	-1.08 ± 0.34	-	-	-
RPE	-0.16 ± 0.17	-0.80 ± 0.71	0.53 ± 0.38	1.04 ± 0.23	-0.21 ± 0.38	-1.07 ± 0.28	-3.61 ± 1.41	-	-

ACC = Acceleration; DEC = Deceleration; HSR = High-speed running; %HRmax = percentage of maximal heart rate; RPE = Rate of perceived exertion. Absent values correspond to variables without comparison to achieve z-score values.

Discussion

The purpose of this review was to present information regarding external and internal training load imposed to soccer players during a microcycle structure. In this review, acceleration and deceleration, average speed, high-speed running, player load, sprints and total distance were the external load measured variables, while the internal load measurements reported results from percentage of maximal heart rate and rate of perceived exertion (RPE). In previous research, associations were found between different measurement methods to quantify external and training load. For instance, Casamichana et al. (12) reported significant associations between session-RPE (s-RPE) and Edwards method (sum of time spent in arbitrary heart rate-zones weighted multiplying the accumulated time in each heart rate zone), a heart rate based indicator, similarly to results presented in other study (104). Additionally, the same study found significant relations between s-RPE and several external training load measurements such as total distance, player load and frequency of efforts at high-intensity. Relationships between external training load measures derived from GPS and accelerometers also had moderate to large relationships with internal training load measures such as s-RPE and heart rate methods (57). These relations may lead to the conclusion that if different variables associate with each other, training demands could also present similarities.

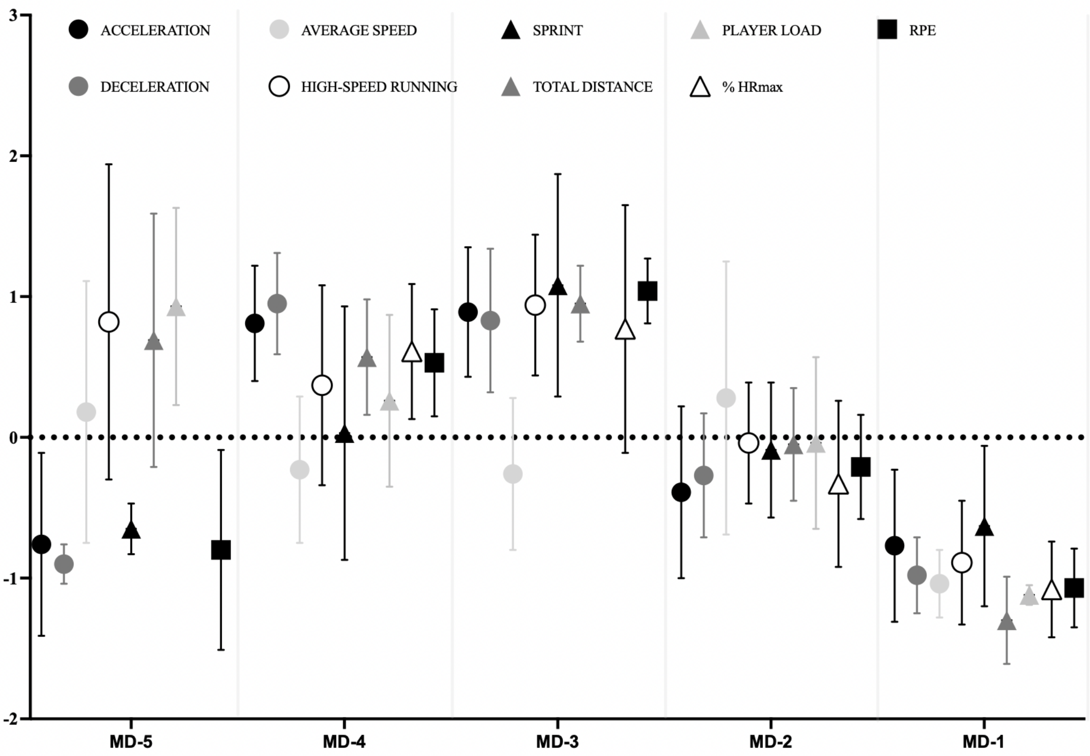

Figure 6. Forest plot displaying the Z-Score (standard deviation) for all variables analyzed (acceleration, deceleration, average speed, high-speed running, sprint, total distance, player load, percentage of maximal heart rate (%HRmax), rate of perceived exertion (RPE)) during the microcycle presented with the different training.

Those similarities were found in this review and are the main finding of this work. Across all measurement methods, training demands tend to decrease as match day approaches. The peak load of the week may vary between different training sessions, but it is usually present in the middle of the week. Moreover, in figure 6, the training week load is represented with a wave effect, increasing the load through the middle of the week (MD-4 and MD-3) and decreasing as match day approaches (MD-2 and MD-1) with the exception of average speed. MD-1 was the least demanding session of the week for almost variables in all studies analyzed. Similar results were reported when analyzing total distance and RPE, in elite soccer players (74). This was also found in futsal (105), volleyball (106) and basketball (107) and can be justified with an intention of practitioners to prescribe a taper session (108).

Match preparedness is not the only concern for coaches, as player's recovery from matches also plays an important role when planning the microcycle sessions. In this review, it was not our objective to quantify match demands, but we report that data when it was presented. As so, match day mostly represented the highest demanding day of the week, except for acceleration and deceleration demands in goalkeepers training. Higher intensity activities were also reported during matches in comparison with training weeks (109). Increasingly, Stevens et al. (110) compared training demands between starters and non-starters and found that non-starters training had a lower weekly total load, which highlights the match contribution to higher week demands. These higher loads may result in overloading and increased injury risk, although it appears that the crucial detail may be in the balance of acute and chronic loads (111,112).

Furthermore, since post-match muscle damage and neuromuscular impairments remain elevated up to 48h (113) and 72h match (38), recovery strategies should be implemented, avoiding high training demands in match subsequent training sessions. This appear to be the case as showed by the answers to an online survey about training and recovery scheduling (108). In the latter study, practitioners indicated 2 designated days for recovery strategies, directing the primary training stimuli to the following training sessions with the exclusion of MD-1.

In our analysis, we found the majority of higher demanding sessions between MD-5 and MD-2 training sessions. According to the tactical periodization, these training sessions refer to acquisition days. For instance, smaller formats of small-sided games were proposed to MD-4 session, resulting in increased number of accelerations (72). In our review, we found that MD-4 was the second most demanding session of the week for accelerations. Other suggestions were presented, such as four against four (4vs.4) small-sided game format, that appears to have similar demands of the match and so, could be applied during training sessions in the middle-week (114).

To develop physiological capacities, players will need to be confronted to high intensities activities during training sessions. For example, better aerobic fitness responses were reported with higher distances covered at high speed and with higher time spent in high-intensity heart rate zones (115). This is supported in our findings, with higher demands in MD-3 training session for high-speed running, sprints, and percentage of maximal heart rate. As so, it could be expected for coaches to aim at players' capabilities development in training sessions distant from matches.

As previously stated, training loads should be managed with particular attention. Too low training loads can induce a detraining effect, while excessive loading can lead do diminished performance and increased injury risk (116). Other practical issue to consider when planning the training week is the day off. Typically, that day of the week, without training session, is located within the first 48h post-match, but no "one size fits all" approach should be applied (117). Recovery sessions should follow match day, but day off can replace one of those sessions. Additionally, the remaining session can be used for players' recovery or compensation. In this review, one study (69) use this approach, by trying to replicate match demands to players with less than 60 min played during previous match, while other players performed a recovery session. This division is also important because different demands are elicited to different players. We also found different training demands for starters and non-starters goalkeepers, with the latter group exposed to lower demands (30). Similar differences were also found in other studies (96,110,118).

In scientific research, identifying the purpose of the training session, especially in MD+1, may help investigators to achieve more clear conclusions. This is a limitation in our review and can probably justify the contrasting findings in MD+1 session. This session was identified as the most demanding in average speed measurement method, but that could be explained by the smaller duration of those sessions and the measurement of average speed as meters per min (91,92). Additionally, the training organization, microcycle, presented variations across the studied papers. For example, one study (99) presented the week as MD-6, MD-4, MD-3, MD-2 and MD-1 organization, and other (101) described the microcycle with MD+1, MD+2, MD-5, MD-4, MD-3, MD-2 and MD-1. These differences difficult a more proficient comparison within the training week and we propose that training sessions should be described and classify according to its main goal, in addition with the identification of the day off as part of the week. As an example of a 7-day training week, a microcycle could be presented as: MD+1, day off, MD-4, MD-3, MD-2, MD-1, MD. Furthermore, both the day plus and the day minus approaches are important to practitioners when analyzing training data.

Different thresholds categorization was also a limitation observed in this review and has been previously discussed in the literature. Sweeting et al. (19) highlighted the lack of consensus and justification for some established thresholds and recommended equal bandwidths when measuring velocity and acceleration efforts. Additionally, we must be careful when interpreting results because approaches to data collection (e.g., number of GPS satellites available, Doppler technique use, sampling frequency, accelerations values directly related to the time window, signal-filtering technique used) and procedure reporting are not always the same (14,119).

Conclusions

In conclusion, training demands in soccer training appear to decrease as match day approaches. As so, middle of the week training sessions elicits higher demands than training sessions immediately before and after the match. Increasingly, the training week load can resemble with a wave, with loads increasing after the match through the middle of the week (MD-4 and MD-3) and decreasing as match day approaches (MD-2 and MD-1).

Practical Applications	When planning a microcycle, coaches aim to players' preparedness to the following match and recovery from the preceding one. Since match appears to be the most demanding session of the week, lower training demands should be imposed to players in training days immediately following and preceding matches. MD-1 session can be used as a taper strategy, while MD+1 can be used as recovery for starters and compensation for non-starters. The remaining sessions of the week can be designated to acquisition and increase players' physiological capacities. Mainly, MD-3 session appears to be the chosen session to apply the greatest demand of the week.

4.2. Study II (Acceleration and deceleration demands during training sessions in soccer: a systematic review)

Citation: Silva H, Nakamura FY, Beato M, Marcelino R. Acceleration and deceleration demands during training sessions in football: a systematic review. Science and Medicine in Football. Jun 26:1-16. DOI: 10.1080/24733938.2022.2090600

Abstract

The aim of this review is to summarize the current scientific knowledge about acceleration and deceleration demands during soccer training. A systematic search of three electronic databases (PubMed, SPORTDiscus, Web of Science) was performed to identify peer-reviewed relevant English-language articles, following PRISMA guidelines. All acceleration and deceleration data were analyzed and organized into four categories: i) training drills variables (i.e. manipulated drills variables such as number of players in small-sided games), ii) training exercises (i.e. different drills such small games or circuit training), iii) players' positions (i.e. demands for each playing position) and iv) training schedule (i.e. training sessions presented as microcycles, season sections or full season). Full-text articles of 42 studies were included in the final analysis. Players' level included: amateur, youth, semi-professional, professional and elite players. All playing positions were considered, including goalkeepers. Six different global position systems brands were used, with the majority measuring data at 10 Hz. Different thresholds and intensities were used in several papers. Lower acceleration and deceleration intensities occurred more often than higher intensities in all four categories. Different exercises elicit different demands and small-sided games presented higher acceleration and deceleration demands than circuit training and other running based drills. Furthermore, manipulating drills variables, as reducing or increasing number of players in small-sided games increase or decrease demands, respectively. Additionally, wide playing positions, such as fullbacks, are generally exposed to higher acceleration and deceleration demands. From a planning point of view, acceleration and deceleration demands decrease as match day approaches.

Keywords:

Small-sided game, training load, training drills, GPS, soccer, microcycle

Introduction

Soccer is an intermittent sport in which players repeatedly perform low and high intensity activities, with concomitant sport specific technical actions (120,121). Players need to perform many accelerations (ACC) and decelerations (DEC) during the match which impact the players' physical level and their performance during the final minutes of the game (79). ACC and DEC are categorized as external training load and are usually monitored with Global Positioning System (GPS) technology (16,18,122,123). The importance of ACC and DEC for competition has been highlighted due to the high mechanical and metabolic demand of these actions which players have to perform repeatedly (124,125). The load from ACC and DEC constitutes a considerable portion of the total load for a player during match play (126) and are associated with post-match muscle damage and fatigue indicated by changes in creatine kinase (increase) and countermovement jump performance (decrement) during recovery time (113). This may be justified because ACC and DEC elicit higher metabolic and mechanical loads than constant speed running in soccer players (127–129).

To be physically prepared for the match, players must train to develop specific physical skills (e.g., lower limb muscle power, ability to change direction). The knowledge of such match demands can lead professionals to apply the approach “train as you play” (130); however, it appears that soccer players frequently do not train with the same intensity as they compete, because higher physiological demands were found during competition than during training sessions (131,132). This is particularly true since many variables that are present in soccer training can affect ACC and DEC volume and intensity such as soccer drills used, players’ positions and coaching philosophy (133). For instance, previous studies found that the distances performed during ACC and DEC could differentiate between positions during training, where higher distances were reported for central midfielders and lower distances for central defenders (26). Moreover, different ACC and DEC demands were found with variations in playing formations across different playing positions (134). Since training specificity is important to improve performance and secure optimal adaptation (135), a review on ACC and DEC demands during training may grant key information for coaches and practitioners, which could better plan and structure their training sessions.

Despite the great interest in ACC and DEC demands in soccer during the recent years, to the best of our knowledge, there is a lack of a practical and concise approach in scientific research that can summarize this important topic. Due to the importance of ACC and DEC in physical performance and training load, a systematic review on this topic can help practitioners and researchers in training design and in data analysis. Variations in ACC and DEC demands across a training week (with reference to the match day) and in different players' positions have not been systematically reviewed to date. These items, as well as different exercises and their variables adaptation to specific objectives, are the four main categories of both planning soccer training and conducting scientific research. Therefore, the aim of this review is to summarize the current scientific knowledge about ACC and DEC demands during soccer training.

Methods

The current review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis) guidelines (49) and is described in Figure 7.

Search strategy

Systematic searches of three electronic databases (PubMed, SPORTDiscus, Web of Science) were conducted to identify peer-reviewed articles published in the English language between 1 January 2010 and 30 June 2020. Initial search was performed in different days for each electronic database (PubMed: June 26, 2020; SPORTDiscus: June 30, 2020; Web Of Science: June 28, 2020). Search terms were accelerat* and decelerat* with "AND" and "OR" with related terms as presented in Table 5. The selection of the terms presented was based in two factors: from reviews and original articles keywords previously read; and from preliminary search of terms in databases.

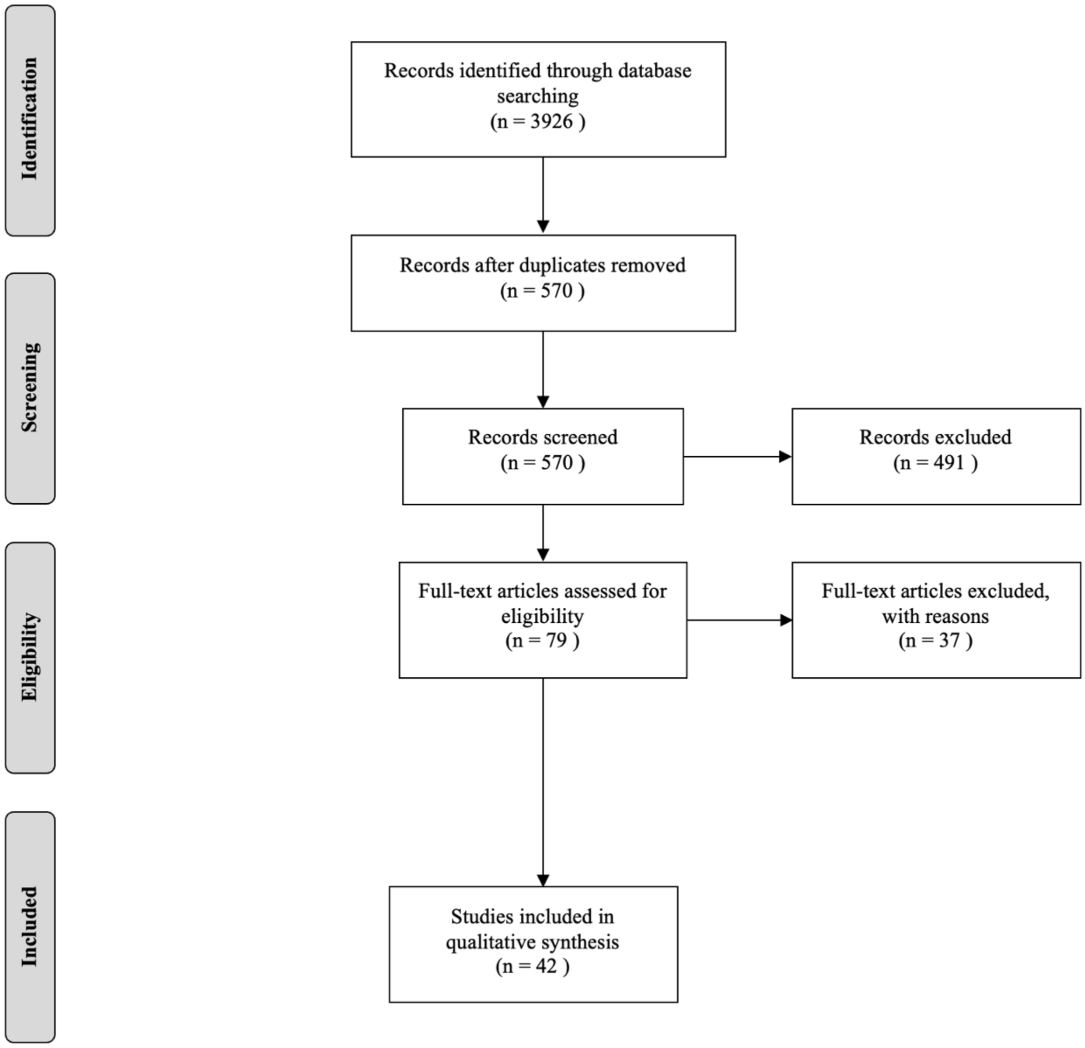

Figure 7. PRISMA flow diagram

Table 5. Database search strategy

Key search terms	Related search terms
1. Accelerat* OR Decelerat*	3. GPS OR external load OR tracking system OR time-motion OR movement profile OR training load OR microcycle OR small-sided games
2. Soccer OR Football	
Search: 1 AND 2 AND 3	

Studies screening

All search results were initially exported to Microsoft Excel (Microsoft, Redmond, WA, USA). Eligible studies were identified throughout different steps. First, duplicates were removed, after confirmation of title, year and author(s). Then, title and abstract were analyzed according to exclusion criteria reported in Table 6 and if any of these were clearly present the study was excluded. If an abstract was not clear for exclusion, the article remained selected for the next stage. In the final stage, studies were fully analyzed and excluded if exclusion criteria were met, or inclusion criteria were absent.

Table 6. Inclusion-Exclusion criteria

	Inclusion criteria	**Exclusion criteria**
1	Original research articles	Reviews; books; letters to editors; conferences; magazines or journals; periodicals; unpublished; non-peer-reviewed.
2	Soccer training	Other sports; only match (official, friendly or simulation) data; single exercise trial used to define thresholds, validate equipment or tests.
3	Able soccer players with mean age ≥ 15 years old	Athletes of other sports; recreational players; referees; players <15 years old; athletes with physical or mental disability; data relative only to one player.
4	GPS systems (with or without accelerometers) identified	Acceleration data provided exclusively by accelerometer; any non-GPS system (e.g. video-based tracking); GPS Hz information not provided; players used additional equipment other than GPS, accelerometer or heart-rate bands/straps (e.g. sled).
5	Clear and identifiable acceleration data provided as external training load	Only player-load or acceleration load data; training data is merged with match data; acceleration presented only as percentage or effects sizes in relation to other variable; acceleration scale not clearly defined.

GPS=global positioning system

Risk of bias

The risk of bias assessment followed Cochrane recommendations and used the Risk Of Bias In Non-Randomized Studies of Interventions tool (ROBINS-I) (50). This tool uses different domains that results in a classification of low, moderate, serious, or crucial risk of bias for each domain and an overall assessment of each study. Domains of ROBINS-I are: 1) Bias due to confounding; 2) Bias due to selection of participants; 3) Bias in classification of interventions; 4) Bias due to deviations from intended interventions; 5) Bias due to missing data; 6) Bias in measurement of outcomes; 7) Bias in selection of the reported result. Finally, an overall risk of bias is provided. To perform this assessment, each study was analyzed by two authors, with a third author resolving disagreements, following the guidelines from the detailed guidance (87). Since this review includes a high number of studies, we chose to provide a summary plot (Figure 8), with each domain and the overall risk of bias assessment. To do so, we used Risk-of-bias VISualization (robvis) (88).

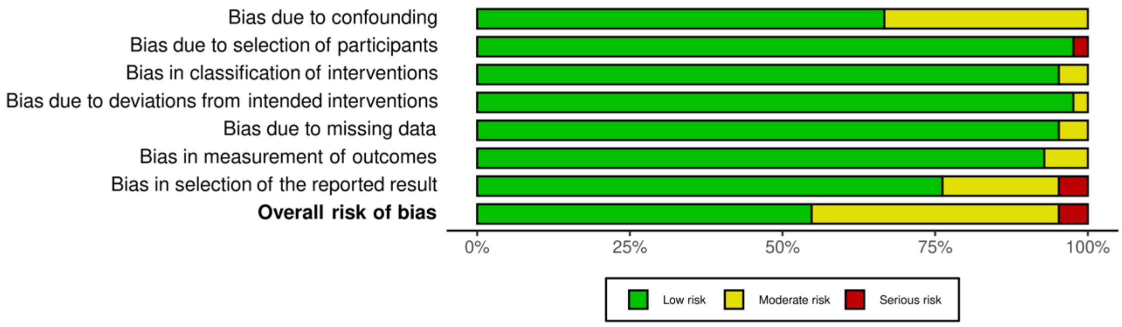

Figure 8. Summary plot of the risk of bias for each seven domains and the overall risk of bias ROBINS-I tool.

Statistical analysis

This systematic review does not have any meta-analysis or statistical analysis between studies because different GPS brands, different ACC and DEC metrics, different ACC and DEC thresholds were used. The authors decided that the risk of bias for a meta-analysis and related between analyses were too high and any analysis could have been biased.

Results

Search results

Figure 7 reports the selection of 42 studies for this review from a total of 3926 articles. Two of the selected studies were not sufficiently clear in their ACC data and the corresponding authors were contacted via e-mail for further information. Information was provided and both studies were included in this review. This review does not differentiate between GPS and Global Navigation Satellite System technology (123).

Studies characteristics

Descriptive characteristics of the selected 42 studies are presented in tables 7 and 8 (due to the several included studies, two tables were created, dividing the studies characteristics into year, sample and analyzed variable of each study [Table 7], and acceleration data, acceleration scale and study's conclusions [Table 8]). Regarding samples, the main level categories were professional level (36%, *n*=15) and elite (17%, n=7). From the 835 soccer players, 56 (7%) are female soccer players. Average ages from all studies ranged between 16 and 28 years old. Player positions were identified in different studies, including goalkeepers. Different equipment was used by the selected studies, with the majority, 69% (*n*=29), using GPS with a sampling frequency of 10 Hz, followed by 17% that used 15 Hz (*n*=7), 7% (*n*=3) using 18 Hz, 5% (*n*=2) using 20 Hz and 2% (*n*=1) using 5 Hz. One study adopted 15 Hz sampling frequency for other variables but used 5 Hz when collecting ACC data (136).

Acceleration and deceleration measurements and thresholds

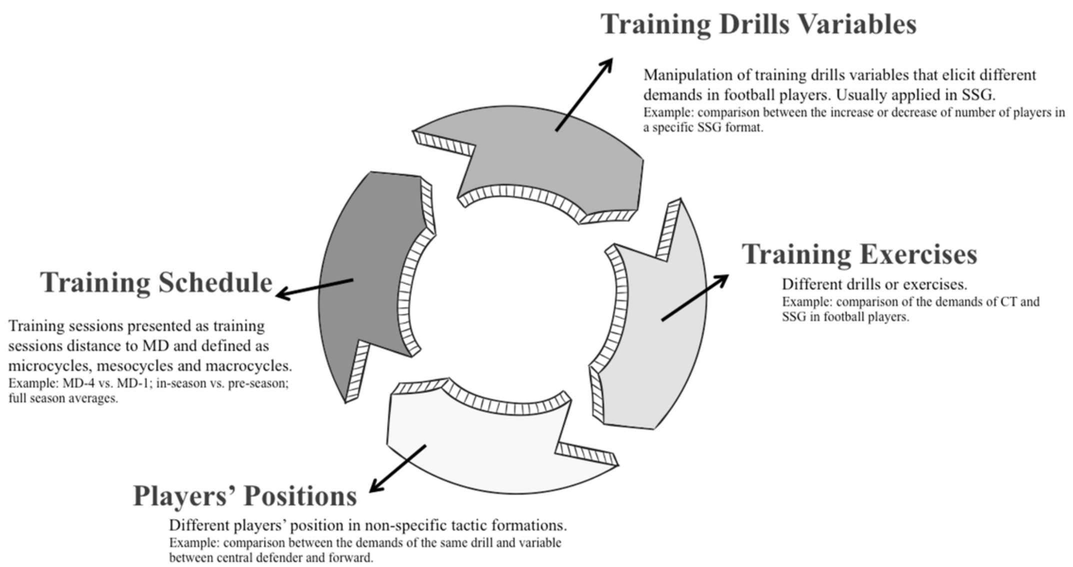

Figure 9. Categories for data analysis.

SSG=Small-sided games; CT=Circuit training; MD=Match day; MD-4=Match day minus 4 days; MD-1=Match day minus 1 day.

21% (*n*=9) of the 42 selected studies did not provide DEC data. The presented ACC/DEC data was analyzed through different variables. Additionally, different intensity thresholds were used to measure ACC and DEC, which are detailed in Table 9. To fill this gap, we created 4 main categories to interpret the data: i) training drills variables (i.e. manipulated drills variables such as number of players in small-sided games), ii) training exercises (i.e. different drills such small games or circuit training), iii) players' positions (i.e. demands for each playing position) and iv) training schedule (i.e. training sessions presented as microcycles, season sections or full season) (Figure 9)

Table 7. Descriptive data (year, purpose, sample and variable for each study) of the selected studies.

Study	Year	Purpose	Sample	Variable
Giménez et al. (28)	2020	Investigate relationship among physical demands of Friendly Matches (2) and 3 different training sessions	n=14 male professional age=23.2±2.7	Friendly Matches; Training 1 (SSG + Mini-goals Large Sided Game), 2 (SSG + circuit training + long sided game), 3 (mini-goal + circuit training + long sided game)
Martín-García et al. (32)	2020	Compare physical demands of different SSG according to player field position and the most demanding passages of matches	n=25 male age=20.4±2.1	Match demanding passages (MDP) vs. 4x4+3 vs. 5vs5+3 vs. 7v7+3 vs. 8vs8+3 according to player position
Owen et al. (137)	2020	Quantify association between 5x5 SSG and Yo-YoIR1	n=23 elite age=25.3±3.1	5x5 and Yo-YoIR1
Querido and Clemente (94)	2020	Characterize microcycle (Internal/External Load) and identify effects of SSG and strength training	n=15 male elite age=18.55±0.39	Microcycle (each training session presented different SSG - identified with intervals)
Sannicandro et al. (138)	2020	Compare the external training load of different SSG formats	n=22 male professional age=24.7±3.9	SSG (5x5, 6x6, 7x7, all with GK)+wildcard players
Zurutuza et al. (139)	2020	Investigate the structure of interrelationships among external/internal training intensity metrics and how these vary depending on game format	n=23 male semi-professional age=25.1±3.7	SSG vs. MSG vs. LSG vs. Simulated Game
Campos-Vásquez et al. (78)	2019	Compare demands of Friendly Matches & Training Sessions during Pre-Season	n=22 male professional age=28.1±4.7	Friendly Matches; Different Training Sessions (Tactical; Fitness, Pre-match activation; Fitness reserves)
Castagna et al. (140)	2019	Examine the internal/external load imposed by Long Sprint Ability oriented SSG using different players-to-pitch area ratio (densities)	n=19 male professional academy-level age=17.1±0.3	SSG300m vs. 200m vs. 100m
Castillo et al. (141)	2019	Analyze external load of 3 different training sessions with competitive match	n=16 male professional age=21.0±0.6	Training 1 (neuromuscular); Training 2 (endurance); Training 3 (speed); Match

Study	Year	Purpose	Sample	Variable
Clemente et al. (142)	2019	Analyze the variations of internal/external load between and within intermittent regimens (6x3' and 3x6') during SSG	n=10 male amateur age=23.7±1.1	6x3' vs. 3x6' and each set separately
Curtis et al. (143)	2019	Quantify and compare season total workload by starter vs. reserve	n=22 male collegiate age=20±2	Total, Match and training workloads
Giménez et al. (31)	2019	Predict the cut-off point values that best differentiate the physical demands of different training drills (SSG, LSG, MG, and CT) and match	n=14 professional male age=23.2±2.7	SSG vs. MG vs. CT vs. LSG vs. Friendly Match
Halouani et al. (144)	2019	Investigate the effects of the SSG-Stop Ball compared to SSG-Small Goals on physical responses	n=16 young male age=18.3±0.7	4x4 SSG Stop-Ball vs. 4x4 SSG Small Goals
Jara et al. (36)	2019	Analyze how modification of SSG pitch size affects the physical demands of GK	n=3 professional male age=24.5±7.2	Small Pitch vs. Medium vs. Large
Madison et al. (25)	2019	Determine the effects of small sided game (SSG) variations on hamstring torque	n=10 male semi-professional age=23±5	SSG (3x3; 300m^2) vs. LSG (4x4; 1000m^2)
Martín-García et al. (35)	2019	Determine the differences between four training games and competitive matches according to position and compared to the most demanding passages of match	n=21 age=20.4±1.2	5x5 vs. 6x6 vs. 9x9 vs. 10x10 (all with GK) vs. match
Moreno-Pérez et al. (30)	2019	External Load GK	n=20 male professional age=27.6±2.0	Training Load during 2 Microcycles
Rábano-Muñoz et al. (145)	2019	Compare demands of a SSG in different ages groups	n=30 male age=24.09±3.51 (senior); 17.83±0.85 (U-19) age=15.97±0.58 (U-17)	SSG (4x4+2 floaters) in U17, U19 and senior
Ramos et al. (34)	2019	Compare activities profile of different training activities with competitive match	n=21 female national players age=26±3.6	Match vs. Warm-up vs. SSG vs. technical/tactical vs. friendly match
Casamichana et al. (146)	2018	Investigate the effect of pitch shape on heart rate and time-motion during SSG	n=20 male amateur age=21±5	5x5 (short narrow pitch vs. short wide vs. long narrow vs. long wide)
Clemente (147)	2018	Test associations between wellness and Internal/External Load during 2 SSG	n=10 male amateur age=19.8±1.6	SSG 5x5 in two different regimens (3x6' vs. 6x3')

Study	Year	Purpose	Sample	Variable
Giménez et al. (148)	2018	Investigate the influence of n. º of touches on SSG physical responses	n=14 male professional age=23.2±2.7	4x4 (1 touch vs. 2 touches vs. free touches)
Giménez and Gomez (27)	2018	Investigate and compare different physical variables and load indicators of 2 SSG and ball circuit training	n=14 male professional age=23.2±2.7	SSG, Mini-Goal Game, Circuit, Match simulation
Gómez et al. (33)	2018	Study and compare the demands imposed on wildcard and regular players in different positional games (4v4+3, 5v5+3, 7v7+3 and 8v8+3)	n=25 age=20.5±1.8	4v4+3, 5v5+3, 7v7+3 and 8v8+3 (regular vs. wildcard)
Gómez-Carmona et al. (21)	2018	Characterize External/Internal Load of matches and SSG related to their objective; compare SSG; and analyze SSG requirements to matches	n=20 national level age=17.32±0.87	Match & 4 different SSG (6x6 with different objectives)
Martín-García et al. (69)	2018	Determine External Load across player position and relative to competition and a microcycle; examine variation in soccer players in MD+1	n=24 professional age=20±2	Microcycle (MD+1 divided in players who competed >60' and others)
Praça et al. (149)	2018	Analyze the influence of SSG variables in physical demands of SSG	n=18 male young age=16.4±0.4	3x3 vs. 4x3 (+ floater) with GK. Players divided by tactical knowledge test results (G1vsG2)
Castagna et al. (150)	2017	Examine the effects of Running Drills & SSG as Long Sprint Ability on internal/external load	n=14 male academy level age=17.6±0.61	Difference between Running Drills and SSG (1x1) in Maintenance (work:rest 1:2) and Production (1:5)
Coutinho et al. (151)	2017	Examine the effects of mental fatigue and additional corridor and pitch sector lines on players' physical and tactical performances during SSG		With mental fatigue vs. non-fatigued opponents in normal pitch and with vs. without mental fatigue with reference lines
Giménez et al. (152)	2017	Compare the movement patterns during SSG, LSG and FM	n=14 male professional age=23.2±2.7	Friendly Match vs. SSG (4x4) vs. LSG (8x8)
Malone et al. (153)	2017	Impact pre-training performance and CK status on subsequent training performance	n=30 male elite age=25.3±3.1	ACC presented as season average and session intensity (relatively)
Akenhead et al. (26)	2016	Describe external load during 1 season 1-game weeks	n=33 male professional age=24±4	Data per training day and per player position

Study	Year	Purpose	Sample	Variable
Mara et al. (136)	2016	Investigate the physical and physiological response to different formats of SSG	n=18 female elite age=24.3±4.2	SSG (4x4 & 5x5), MSG (6x6 & 7x7), LSG (8x8 & 9x9)
Gaudino et al. (67)	2015	Identify most influential external load markers on session RPE	n=22 male elite age=26±6	Average of complete season
Mara et al. (154)	2015	Investigate the variation in training demands, physical performance and player wellbeing across a female soccer season	n=17 female elite age=16.4±0.7	Preseason vs. early season vs. late season
Praça et al. (155)	2015	Compare physical demands of 3x3, 4x3 and 3x3+2	n=18 young male age=-	SSG 3x3 vs. 3x3+2 vs 4x3 (GK included in all)
Ade et al. (22)	2014	Quantify physiological responses, time-motion characteristics of Speed-Endurance-Production and Speed-Endurance-Maintenance drills	n=16 elite male youth age=17±1	Running Production (30:60") and Maintenance (120:60") vs. SSG Production (1vs1 30:60") and Maintenance (2x2 120:60")
Casamichana et al. (156)	2014	Examine the effect of exercise duration and n. º of touches during SSG	n=12 male semi-professional age=22.7±4.3	6x6 free vs. 6x6 with 2 touches max; 12' divided (6'+6')
Fuentes et al. (157)	2014	Observe the evolution of the external load of a player return to training after injury	n=13 male age=20.9±1.7	Difference between team and injury player for each day
Gaudino et al. (158)	2014	Influence of SSG variables in physical demands of SSG	n=26 male age=26±5	5x5 vs. 7x7 vs. 10x10 (possession only vs. regular play with GK)
Hodgson et al. (159)	2014	Quantify characteristics and technical demands of (SSG) played on small, medium and large pitches	n=8 university level age=20±1	Small (30x20) vs. Medium (40x30) vs. Large (50vs40)
Castellano et al. (160)	2013	Influence of SSG variables in physical demands of SSG	n=14 male semi-professional age=21.3±2.3	3x3 vs. 5x5 vs. 7vs7 (with GK vs. with small goals vs. possession)

Table 8. Descriptive data (year, purpose, sample and variable for each study) of the selected studies.

Study	Acceleration Data	Acceleration Scale (thresholds)	Conclusion
Giménez et al. (28)	No. ACC & DEC	ACC & DEC between 2m·s^2 intervals	Training routines did not replicate the main set of high intensity efforts experienced in competitive conditions
Martín-García et al. (32)	Frequency (rep/min) ACC & DEC	ACC & DEC > 3m·s^{-2}	Distance, distance covered at high speed and distance covered when sprinting are the variables that have the lowest MDP percentage while performing the games studied

Study	Acceleration Data	Acceleration Scale (thresholds)	Conclusion
Owen et al. (137)	No. ACC & DEC	ACC & DEC (≥3.3 $m·s^{-2}$)	5 vs. 5 SSG assessment protocol can be utilized more regularly by coaches as aerobic fitness testing to assess the intermittent aerobic capacity of elite soccer players
Querido and Clemente (94)	Frequency (rep/min) ACC & DEC	ACC>2 $m·s^{-2}$/min & >4 $m·s^{-2}$/min & DEC>2 $m·s^{-2}$/min & >4 $m·s^{-2}$/min	External load monitoring revealed that MD-4 had the highest values of ACC and DEC > 2 $m·s^{2}$ /min
Sannicandro et al. (138)	Max ACC & DEC; No. ACC & DEC	ACC>2.5 $m·s^{-2}$ DEC<2.5 $m·s^{-2}$	Significantly more ACC events were detected in the 5vs5 format whereas the number of DEC was significantly greater in the 6vs6 compared with the 7vs7 format
Zurutuza et al. (139)	Distance ACC & DEC	ACC & DEC (>2 $m·s^{-2}$)	ACC and DEC component was the most stimulated in SSG, the cardiovascular demands were highest in MSG, and peak and average velocity were most demanded in LSG and SG
Campos-Vásquez et al. (78)	Distance ACC & DEC per hour	Moderate: 2-3 $m·s^{-2}$; and High: >3 $m·s^{-2}$ ACC & DEC	Friendly matches produce the highest loaded training stimulus across the preseason period
Castagna et al. (140)	Distance ACC & DEC	ACC & DEC (≥2 $m·s^{-2}$)	During the SSG300m the players attained external and internal load values that were practically higher than those achieved during the other formats
Castillo et al. (141)	No. High ACC per minute	ACC > 3 $m·s^{-2}$	External loads were higher during matches when compared with acquisition training sessions
Clemente et al. (142)	Frequency (rep/min) ACC & DEC	ACC & DEC (>2 $m·s^{-2}$)	Shorter sets (6x3') almost certainly largely increased total and running distances and very likely moderately and largely increased total ACC and DEC; increases in RPE were found in longer sets
Curtis et al. (143)	No. ACC in four zones	AZ1, 0–0.99 $m·s^{-2}$; AZ2, 1–1.99 $m·s^{-2}$; AZ3, 2–2.99 $m·s^{-2}$; and AZ4, .3 $m·s^{-2}$	Starters accumulated substantially more total physical and physiological workloads over the season
Giménez et al. (31)	No. ACC & DEC	ACC & DEC (>2 $m·s^{-2}$)	Training and match tasks place different demands on soccer players in terms of running, deceleration, acceleration and maximal velocity reached
Halouani et al. (144)	No. ACC & DEC	ACC & DEC 2-3 $m·s^{-2}$ & > 3 $m·s^{-2}$	SSG-Stop Ball induced higher physical and HR values than the SSG-Small Goals
Jara et al. (36)	No. ACC & DEC	ACC & DEC > 3 $m·s^{-2}$	Intensities were lower when the pitch size was larger and pitch exploration variables increased along with the increment of the pitch size
Madison et al. (25)	Total No. ACC & DEC	ACC >1 $m·s^{-2}$ & DEC >-1 $m·s^{-2}$	Larger relative area SSG elicited the greatest internal and external loads, resulting in decrements in hamstring force
Martín-García et al. (35)	Frequency (rep/min) ACC & DEC (all and by position)	ACC & DEC > 3 $m·s^{-2}$	As the SSG format increases, all the rest of the variables increase and the number of cases with significant interposition differences also increases

Study	Acceleration Data	Acceleration Scale (thresholds)	Conclusion
Moreno-Pérez et al. (30)	No. High & Low ACC & DEC	ACC > 3 m·s^{-2} DEC < 3 m·s^{-2}	External load was progressively decreased in the days before match and habitual GK training has an excess of ACC/DEC
Rábano-Muñoz et al. (145)	Distance ACC & DEC	ACC > 2.5 m·s^{-2} DEC < 2.5 m·s^{-2}	Demands of the SSG are determined by the age of the players and regular players have greater demands than floater players in the SSG utilized
Ramos et al. (34)	Frequency (rep/min) ACC & DEC	All between </> 2.5 m·s^{-2}	There were different ACC and DEC demands amongst different activities and only friendly match activity was replicated or exceeded matches
Casamichana et al. (146)	No. ACC & DEC	ACC & DEC Moderate (> 3 m·s^{-2}) and High (> 4 m·s^{-2})	Modifying length places greater physiological demands on players than modifying width
Clemente (147)	Total No. ACC	ACC > 2 m·s^{-2}	Wellness status may influence workload in SSG; in particular, DOMS may be moderately-to-largely detrimental to both internal and external load variables. Moreover, it was confirmed that RPE is moderately-to-largely correlated to objectively measured external load variables.
Giménez et al. (148)	Distance ACC	ACC 1 (< -4 m·s^{-2}), ACC 2 (-4 to -2 m·s^{-2}), ACC 3 (-2 to 0 m·s^{-2}), ACC 4 (0-2 m·s^{-2}), ACC 5 (2 to 4 m·s^{-2}), and ACC 6 (> 4 m·s^{-2}).	The use of one touch during SSGs increases the time walking and high-intensity ACC
Giménez and Gomez (27)	No. ACC & DEC	ACC & DEC +/-2 m·s^{-2}	Although SSGs, MGs, CT, and MS activities do simulate certain match patterns, it seems that players in SSs engage in more high-intensity activity
Gómez et al. (33)	Frequency (rep/min) ACC & DEC	ACC & DEC > 3 m·s^{-2}	Load imposed on wildcard players is lower than the one imposed on regular players
Gómez-Carmona et al. (21)	Frequency (no./min) Low, Medium and High ACC & DEC	ACC & DEC/min; Low (1-2.5 m·s^{-2}); Medium (2.5-4 m·s^{-2}); High (> 4 m·s^{-2})	The objective of the SSGs directly influenced the demands on the players in training sessions
Martín-García et al. (69)	No. ACC & DEC	ACC & DEC > 3 m·s^{-2}	MD + 1C was more intense than the MD + 1R; loads were greatest in MD-4 with selected metrics approaching competition loads; (c) the external load of the microcycle varied substantially based on the players tactical role in the team, and (d) the coefficient of variation (CV) for weekly training sessions was generally large across all elements of the microcycle.
Praça et al. (149)	No. ACC and Percentage of total distance	ACC > 2 m·s^{-2}	Cognition factors (tactical knowledge) and SSG settings influence athletes' physical and physiological demands during SSG.
Castagna et al. (150)	ACC & DEC distance	ACC & DEC (≥ 2 m·s^{-2})	Generic drills showed superiority over specific drills in inducing Long Sprint Abilities related physiological responses.

Study	Acceleration Data	Acceleration Scale (thresholds)	Conclusion
Coutinho et al. (151)	No. ACC & DEC	ACC & DEC: Low (1-2 $m{\cdot}s^{-2}$); Medium (2-3 $m{\cdot}s^{-2}$); High (> 3 $m{\cdot}s^{-2}$)	Mental fatigue affects the ability to use environmental information and players' positioning, while the additional reference lines may have enhanced the use of less relevant information to guide their actions during the mental fatigue and normal pitch and with condition.
Giménez et al. (152)	No. ACC & DEC	ACC & DEC: 0.0-2.0 $m{\cdot}s^{-2}$; 2.1-4.0 $m{\cdot}s^{-2}$; > 4.0 $m{\cdot}s^{-2}$	SSG do not replicate exactly the movement patterns of a competitive match, but can increase the execution of short-term and high-intensity movements for specialized training.
Malone et al. (153)	Total No. ACC & DEC and ACC & DEC per minute	ACC & DEC > 3 $m{\cdot}s^{-2}$	Training output can be influenced by reduced neuromuscular performance and increased creatine kinase levels
Akenhead et al. (26)	Total No. ACC & DEC	ACC > 1 $m{\cdot}s^{-2}$ & DEC > -1 $m{\cdot}s^{-2}$	Only total distance, ACC and DEC distance were able to differentiate between playing positions and expressing ACC and DEC variables relative to training time and total distance reduced the effect size of inter-day differences and altered the rank-order of training sessions within the microcycle.
Mara et al. (136)	Mean ACC interval and distance; maximum ACC distance; peak speed, peak ACC and recovery duration; commencement and final velocities	ACC (≥ 2 $m{\cdot}s^{-2}$)	Coaches can manipulate sprinting, HSR, ACC profiles, heart rate and metabolic demands by concurrently modifying the number of players and field dimensions in elite female soccer training games
Gaudino et al. (67)	No. ACC & DEC No. ACC & DEC per minute	ACC & DEC > 3 $m{\cdot}s^{-2}$	The external-load measures that were found to be moderately predictive of RPE-TL in soccer training were HSR distance and the number of impacts and ACC
Mara et al. (154)	No. ACC & DEC	ACC & DEC (≥ 2 $m{\cdot}s^{-2}$)	Training demands fluctuated between preseason and early season, with observed declines in all training variables following preseason
Praça et al. (155)	No. ACC and Percentage of total distance	ACC 1: > 2 $m{\cdot}s^{-2}$; > 2.5 $m{\cdot}s^{-2}$	A reduction in physical demands was observed for small-sided games performed in unbalanced situations (4vs.3)
Ade et al. (22)	Distance ACC & DEC	High ACC & DEC: 2-3 $m{\cdot}s^{-2}$ Maximum ACC & DEC: > 3 $m{\cdot}s^{-2}$	The physiological responses were greater in the running drills than in the respective SSG except in ACC and DEC
Casamichana et al. (156)	No. ACC in four zones	ACC zones (1.0-1.4, 1.5-1.9, 2.0-2.4, and ≥2.5 $m{\cdot}s^{-2}$)	SSG with free play touches decrease the intensity of physical parameters during the second 6-min period. During the second period (6-12 min) of SSG with 2 touches there was an increase in HRmean and in the time spent in high exercise intensity zones, but these differences were not observed in SSG free play.

Study	Acceleration Data	Acceleration Scale (thresholds)	Conclusion
Fuentes et al. (157)	No. ACC & DEC in three zones	ACC & DEC 1: 0-2 $m{\cdot}s^{-2}$; 2: 2-3 $m{\cdot}s^{-2}$; 3: 3-5 $m{\cdot}s^{-2}$	Intensity of the training of the injured player was probably too high after a fairly long recovery period of one month
Gaudino et al. (158)	No. & Max ACC & DEC	Moderate (2-3 $m{\cdot}s^{-2}$) & High (>3 $m{\cdot}s^{-2}$) ACC & DEC	SSG represent an appropriate and efficient training mode to stimulate all the specific physical aspects of playing soccer
Hodgson et al. (159)	Distance ACC & DEC	ACC & DEC: Low (1-2 $m{\cdot}s^{-2}$); Medium (2-3 $m{\cdot}s^{-2}$); High (> 3 $m{\cdot}s^{-2}$) Total ACC & DEC (≥ 1 $m{\cdot}s^{-2}$)	Small pitch sizes are characterized by a reduced physical demand and an increased technical demand in comparison to large pitches. Medium pitch sizes seem to be optimal; providing both a high frequency of technical actions, and a high physical demand that is unchanged as pitch size increases
Castellano et al. (160)	No. ACC in four zones	ACC zones (1.0-1.5, 1.5-2.0, 2.0-2.5, and >2.5 $m{\cdot}s^{-2}$)	Changes both in game format and the number of players affect the players' physiological and physical demands

Table 9. Acceleration and deceleration intensities and thresholds from the selected studies.

Intensity classification	Threshold (ACC exclusively or both ACC and DEC)	Studies
No classification	> 1 $m{\cdot}s^{-2}$	(25,26)
	≥ 2 $m{\cdot}s^{-2}$	(136)
	> 2 $m{\cdot}s^{-2}$	(27,28,139,142,147,149,152)
	> 2 $m{\cdot}s^{-2}$ and > $m{\cdot}s^{-2}$	(94)
	> 2.5 $m{\cdot}s^{-2}$	(145)
	> 3 $m{\cdot}s^{-2}$	(26,36,67,144,153)
	≥ 3.3 $m{\cdot}s^{-2}$	(137)
	≥ 4 $m{\cdot}s^{-2}$	(160)
Maximum Intensity	> 3 $m{\cdot}s^{-2}$	(22)
High Intensity/ High ACC/ Intense	> 4 $m{\cdot}s^{-2}$	(21,146)
	> 3 $m{\cdot}s^{-2}$	(26,30,32,33,35,69,78,141,148,151,158,159)
	≥ 2.5 $m{\cdot}s^{-2}$	(138)
	2 to 3 $m{\cdot}s^{-2}$	(22)
	> 2 $m{\cdot}s^{-2}$	(31)
	≥ 2 $m{\cdot}s^{-2}$	(140,150)
Medium/ Moderate Intensity	> 3 $m{\cdot}s^{-2}$	(146)
	2.5 to 4 $m{\cdot}s^{-2}$	(21)
	2 to 3 $m{\cdot}s^{-2}$	(26,78,148,151,158,159)
Low Intensity	1-2.5 $m{\cdot}s^{-2}$	(21)
	1 to 2 $m{\cdot}s^{-2}$	(26,151,159)
Zones/ Intervals/ Levels	< -2.5 $m{\cdot}s^{-2}$, -2.5 to -1 $m{\cdot}s^{-2}$, -1 to 1 $m{\cdot}s^{-2}$, 1 to 2.5 $m{\cdot}s^{-2}$ and > 2.5 $m{\cdot}s^{-2}$	(34)
	1.0 to 1.4 $m{\cdot}s^{-2}$, 1.5 to 1.9 $m{\cdot}s^{-2}$, 2.0 to 2.4 $m{\cdot}s^{-2}$ and ≥ 2.5 $m{\cdot}s^{-2}$	(156)
	0 to 2 $m{\cdot}s^{-2}$, 2 to 3 $m{\cdot}s^{-2}$, 3 to 5 $m{\cdot}s^{-2}$ and 0 to -2 $m{\cdot}s^{-2}$, -2 to -3 $m{\cdot}s^{-2}$, -3 to -5 $m{\cdot}s^{-2}$	(157)
	> 2 $m{\cdot}s^{-2}$ and > 2.5 $m{\cdot}s^{-2}$	(155)
	0 to 0.99 $m{\cdot}s^{-2}$, 1 to 1.99 $m{\cdot}s^{-2}$, 2 to 2.99 $m{\cdot}s^{-2}$ and ≥ 3 $m{\cdot}s^{-2}$	(143)

ACC = Acceleration; DEC = Deceleration. Note: When DEC data was reported, different approaches were used to present information, such as negative values or positive values with specific reference to DEC. For a more proficient analysis, only positive values were presented.

Training drills variables

Typically, SSG formats increase ACC and DEC demands when a reduced number of players (31–33,35,136,138,139,152,158,160) and smaller pitch sizes (25,136,146) are used. However, some exceptions were found for 5vs.5 that had less ACC > 2.5 $m{\cdot}s^{-2}$ than 7vs.7 format (160), while more maximal ACC and DEC were found in 10vs.10 than in 7vs.7 and 5vs.5 (158); finally, short wide pitch size (25x66m) elicited more moderate intensity ACC and high intensity DEC than short narrow size (25x40m) (146). Contrasting results such as higher demands in medium or larger pitches sizes, were also registered, but that can be due to the different measurement used to assess demands (ACC and DEC distance covered) (140,159) or goalkeeper demands (36).

SSG can also be manipulated by changing specific rules; for instance, numerical superiority decreases ACC and DEC demands (149,155), especially for the floaters (33,145,155). Another common rule used during SSG is the number of ball touches allowed; however, this review reports conflicting results were found in this review (21,148,156). SSG are often proposed in two formats, first to maintain the possession of the ball, which reported high demands in one study (144); second, to score goals, which reported more ACC and DEC than possession games in other two studies (158,160). The presence or absence of fatigue was also analyzed and, the only paper reported in this review on this specific topic reported that mental fatigue can affect ACC and DEC demands (151). Finally, drills were also conditioned by the relation of work and rest times. While one study found more ACC in the regimen of 3 sets of 6 minutes than 6 sets of 3 minutes in a 5vs.5 SSG (both with 2 minutes of rest) (147), opposite results were found with the same regimens in another study (142).

Regarding efforts, ACC had higher values in some studies (21,25,31,36,139,140,142,148,152,159), while DEC had in others (35,137,138,144,145,151). Finally, low ACC and DEC intensities occur more frequently than higher intensities (21,148,152,155,159,160).

Training exercises

When comparing training drills and matches, higher ACC and DEC demands were found in SSG (27,31,35,152), in friendly matches (78) and official matches (141).

Matches (official and friendly) imposed higher DEC demands in female players, except in central midfielders, while technical-tactical training elicited higher ACC demands (34). Contrasting with these findings, friendly matches elicited the lowest ACC and DEC demands in comparison with training sessions that included SSG, large-sided games (LSG) and mini-goals games (28). Between training protocols, the same study reported the lower DEC demands in the training session composed with SSG, circuit training and LSG, while the lower ACC demands were found in the training session with mini-goals, circuit training and LSG. Additionally, circuit training was also the least-demanding drill when compared with SSG, LSG, mini-goals games and friendly matches (or match simulations) (27,31). Furthermore, higher ACC and DEC distances were covered during 1vs.1 and 2vs.2 SSG formats than in continuous and shuttle running drills (22,150). In a study investigating female players, warm-up drills and SSG elicited the lowest DEC and ACC demands respectively compared with matches and technical-tactical training (34). Moreover, two studies compared different training sessions with matches and both registered higher demands in matches (78,141). Endurance sessions (with positional games, LSG and match simulation) had higher relative ACC than strength-based (with positional games, SSG and medium sided game) and speed sessions (positional games, LSG, tactical drills and free kicks) (141). Additionally, a further study found lower ACC and DEC demands in tactical sessions and reserves fitness sessions, respectively (78).

More ACC were registered than DEC (22,27,28,31,35,78,150,152), except for tactical training, where high DEC distance per hour (<-3 $m \cdot s^{-2}$) was higher than high accelerations distance per hour (>3 $m \cdot s^{-2}$) (78). Lower intensities were more frequent (22,78,152), except for higher distance covered in maximal DEC (≤-3 $m \cdot s^{-2}$) than high DEC (–2 to -3 $m \cdot s^{-2}$) during 1vs.1 SSG (22).

Players' position

Goalkeeper's demands were analyzed in two studies, reporting higher ACC and DEC demands in the training sessions in the middle of the week (in comparison with matches and other sessions) (30) and in small SSG formats (32x23m > 50x35m) (36).

Players in central positions (central defenders, midfielders and attackers) performed fewer ACC and DEC efforts than in wide positions (fullbacks and wide midfielders) (26,32,34,35,69). Some exceptions were found in attackers with more DEC in 5vs.5 SSG (35); central midfielders in compensatory session (MD+1C), MD-4 and MD-1 (69); and offensive midfielders in LSG (35).

Finally, starters performed more ACC and DEC efforts than non-starters (30).

Training schedule

For studies analyzing the training schedule, this review found that the MD-4 (26,30,94), MD-3 (94) and MD+1C (69) were the most demanding sessions of the week; while MD-1 (26,69,94) was the least demanding, with the exception for goalkeepers which reported the lowest demands during matches (30). One study, that compared training demands of the team with a player during his recovery from an injury, found that team and recovery player had different ACC and DEC demands during the week session (157).

In female players, no microcycle data was available. However, one study divided the season into preseason, the most demanding period of the season, early season, and late season – the least demanding (154).

Overall, this review found that more ACC were reported than DEC (26,30,69,94,153,154), with one exception (153). Lower ACC and DEC intensities occurred more often than higher intensities (94,143,157).

Discussion

The main purpose of this review was to provide a comprehensive summary of ACC and DEC demands during soccer training, which may help practitioners in their daily practice and to establish new lines of research. This review included male and female soccer players at different levels such as professional, semi-professionals, amateurs and youth players. Different players' positions were also analyzed, including goalkeeper, which is not common in this type of review. This review analyzed four main categories to promote a more comprehensive interpretation of different factors and conditions that may influence ACC and DEC: training drills variables, that consider the manipulation of drills variables that might influence ACC and DEC; training exercises, which addresses different exercises choices to implement in training sessions; players' positions, describing ACC and DEC demands according to tactical positions; and finally, training schedule category, which analyzed the training sessions distribution across a microcycle, organized according to the distance to the competition and the organization of that weeks during the season (Figure 3). This systematic review shows that ACC and DEC efforts are influenced by different variables within each of the categories previously presented. Regarding action frequency, ACC actions were more frequent than DEC, independent of the category analyzed. Lower intensities of ACC and DEC efforts tend to occur more often than higher intensities efforts during training sessions. More ACC were found in competition than in training sessions (79,126,161). Regarding the four categories, SSG present higher ACC and DEC demands than other drills such as circuit training, especially when played in smaller formats (by manipulating number of players or pitch size) in comparison with larger formats of SSG; wide playing positions, as fullbacks, may be exposed to more ACC and DEC demands; and finally, middle of the week training sessions are the most demanding sessions of the week regarding ACC and DEC demands and these demands decrease as match day approaches.

Acceleration and deceleration measurements and thresholds

This review reports that the intensity thresholds were not the same across the studies analyzed (Table 9). Without a standardized classification of ACC and DEC thresholds, it is very difficult to perform a comparison among studies or to provide definitive statistical analyses and draw relevant conclusions for practice. Additionally, intensity classification can also be a problem when establishing conclusions. As previously stated, it is important to clarify thresholds and intensities and avoid arbitrary thresholds to classify intensities (20). A solution for this issue was suggested by Abbott et al. (162), who proposed the use of player-based ACC intensity thresholds, as it appears to represent individual intensity more accurately than generic thresholds. Briefly, these authors divided the players in 3 groups (low, medium and high accelerative capacity, obtained as <1, ± 1 and >1 standard deviation from the mean, respectively), according to their maximum ACC testing scores. Abbott et al. categorized ACC intensities as low (25-50%), moderate (50-75%) and high-intensity (>75%) ACC as proposed previously by Sonderegger et al. colleagues (24). In the latter, authors have presented the quantification of ACC percentage which takes in account both maximum voluntary ACC and initial running speeds, however, DEC would still be disregarded in this proposal, as stated by the authors. This approach could offer some benefits such as players' individualization based on their maximal effort, but it could also limit the comparison among players and studies since different thresholds would be used for each player (20).

It would be beneficial for coaches and researchers to have a common approach and to use specific thresholds to better quantify ACC and DEC in soccer. Sweeting et al. (19), reported in their review that there is no justification to the chosen thresholds used in the literature, which is a very important limitation. Since no consensus on how to define ACC and DEC thresholds exist, some findings interpretation could be biased. The same authors recommended thresholds of equal bandwidth to solve this issue. For example, for velocity thresholds, specific bandwidths of 0-5, 5-10, 10-15, 15-20 and >25 $km·h^{-1}$ were proposed, however, no ACC and DEC bandwidths were suggested so far.

Another issue may arise with ACC zones and intensities classification, for example, ACC intensities > 3 $m·s^{-2}$, which could be classified as high or moderate. Considering an example from velocity analysis, it is possible to see that sprints have been previously classified as events > 20 $km·h^{-1}$ and > 25 $km·h^{-1}$ for female and male soccer players respectively (163) and this could be an issue because researchers and practitioners could interpret external loads events using different terminologies (e.g., moderate or high for the same intensity). A second issue could relate to the use of open-ended thresholds, such as > 2 $m·s^{-2}$, > 3 $m·s^{-2}$, > 4 $m·s^{-2}$; considering again velocity analysis, it is possible to find papers reporting open-ended thresholds such as high-speed running > 15 $km·h^{-1}$ and sprint > 25 $km·h^{-1}$, which may lead to biased interpretation of high-intensity demands counted) (13,17). Considering both these issues, this review suggests using specific thresholds bandwidth such as 0-0.99, 1-1·99 $m·s^{-2}$ and so on avoiding using open-ended thresholds; in this way, ACC and DEC quantification could be more accurate and specific. Finally, this review suggests avoiding interpreting ACC and DEC intensities as low, moderate or high, but simply quantifying using specific thresholds.

Training drills variables

SSG drills are very common in soccer training and can be adapted according to coaches' objectives. For instance, an increase in the number of players may lead to fewer technical actions per player (164). Similarly, other variables such as pitch size, rules and work to rest ratio can also be modified to manipulate SSG and aim different training objectives (114). For example, the presence of goalkeepers and floaters elicited more DEC than ACC efforts (138), while the opposite was found without goalkeeper but with floaters (145) (more research is needed on this topic). Practitioners should be aware that the mere inclusion or exclusion of goalkeeper in SSG may increase or decrease the drill intensity (165). In this review, ACC and DEC demands seem to increase as the SSG format decreases in number of players or area per player (25,32,33,35,138,139,146,149,152,155,158). Similar results were found when comparing 4vs.4+goalkeeper SSG and 8vs.8+goalkeeper SSG format (166). However, the implementation of SSG during training present also some limitations: first, they require a high technical and tactical levels to achieve the desired physical intensities (114), second, this can negatively affect the long-term physical development of the players by limiting the intensity during training. Last, floaters (when used during SSG) may need physiological compensation due to their lower ACC and DEC demands reported in previous studies (33,145,155).

Training exercises

Although SSG are very common in soccer, there are several other training exercises used by practitioners. Different training protocols, such as sprint training and speed endurance training, have been shown to improve players' conditioning (167–169). In our review, SSG presented higher ACC and DEC demands than other drills such as continuous and shuttle running (22,150) and circuit training (27). Moreover, when circuit training was present in a training session, ACC and DEC demands were lower than in sessions comprising only SSG (28). Additionally, more DEC but less ACC were recorded in SSG in comparison with warm-ups and tactical-technical training (34). Warm-up also had the lowest training load, monitored with different methods (i.e. rate of perceived exertion and heart rate) but not ACC and DEC, in comparison with technical-tactical training and physical training (programmed session that was devised to enable players to cope with the physical demands of match-play) (170).

Finally, friendly matches or match simulations were also analyzed in this review. This type of training session can be used to simulate competition and regarding ACC and DEC demands, that appears to happen (34,78,141). However, in some other studies, friendly matches reported lower ACC and DEC demands than other drills (28,152). These conflicting results may result from how the friendly matches were conducted, for instance the level of the opponents could play a key role for the demands of the match. As previously said, competition tends to be the most demanding session of the week and it could be expected that friendly matches replicate these intensities, however, many factors could play an important role (such as team's motivation, opponent's level, etc.).

Player's positions

Previous research has highlighted central defender as the position with lowest ACC and DEC demands during matches (126,134,171,172) but contrasting results were also found (173,174). In this review, central defenders reported a lower number of ACC and DEC but not consistently (26,32,34,35,69). Generally, central defender and forwards were predominately less exposed to higher ACC and DEC demands in comparison to fullbacks and midfielders (26,32,34,35,69). Two studies analyzed ACC and DEC during soccer matches and reported more ACC and DEC occurrences for wide players than central players (126,171). Similar results were found in other studies (172,173,175), with wide midfielders and fullbacks performing more ACC than central defenders and midfielders. Instead, in the de Hoyo study (175), strikers (or forwards) were the players with more ACC which could be due to specific tactical demands (e.g., due to counterattack situations created by the team). Since competition demands elicit different demands across player's positions (176), training drills should aim to prepare players to meet these specific requests. For instance, according to the results of this review, external positions such as fullbacks and wide midfielders may require higher physiological preparedness to match the ACC and DEC demands of competition.

Little is known about goalkeeper's ACC and DEC demands in soccer training and this may be because goalkeepers training sessions are mainly based on technical work (177) or actions such as jumping and diving and these demands come with no surprise because of the characteristics of the role (93,178). According to our findings, goalkeepers performed more ACC and DEC in training sessions than in matches.

Training schedule

Considering the training week, ACC and DEC demands decrease as match day approaches and this strategy is frequently used in team sports to avoid pre-match fatigue and increase match preparedness (108,179,180). The middle of the week, MD-4 and MD-3, and the compensation session (MD+1C) were the most demanding sessions and MD-1 the least demanding. Martín-García et al. (69) investigated compensatory and recovery sessions and presented the compensatory session as the most demanding session of the week. These results are aligned with the evidence that defines matches as the most demanding session of the week and the main cause of the training load difference between starters and non-starters (77,96,181). Furthermore, these differences could lead to non-starter players being under-trained (110). In this sense, when conducting a compensatory session for non-starters, high ACC and DEC demands should be planned (to compensate for the load missed during the match). Recovery also plays an important role, as ACC and DEC actions during matches were associated to fatigue that lasted up to 72h after the match (38). As so, in sessions immediately close to the match, training exercises should be carefully chosen, to avoid excessive ACC and DEC demands. For example, small (area and number of players) SSG should be avoided in these days. In this review, ACC actions were predominant in comparison with DEC during training, the opposite of what a recent review revealed when analyzing ACC and DEC demands in matches (29). Finally, soccer players reported a predominance of low intensities in ACC and DEC efforts compared to higher intensity efforts during training sessions, similarly to what happen in competition matches (128,182) - this comes also as no surprise as low intensity activities are more common than high intensity activities.

Limitations and future directions

This review is not without limitations, first, the lack of consensus when establishing ACC and DEC thresholds limits the quality and depth of the analysis. Hence, future research should prioritize the standardization of ACC and DEC intensity thresholds. As previously stated, applying bandwidth zones instead of intensity or zones classification could help improve research data comparison and analysis. As an example, instead of presenting ACC and DEC data as high, moderate and low intensity, one can present the number of ACC and DEC efforts within each bandwidth (0-1 $m·s^{-2}$; 1-2 $m·s^{-2}$; 2-3 $m·s^{-2}$; etc.). With this strategy, comparisons between measurements would be more precise and teams could classify intensities of their own players. However, it is important to notice that this would not be a definitive solution because the assessment of ACC and DEC with GPS is not absent of concerns. As stated by Buchheit et al. (183) ACC and DEC measures can differ between models and between units. Second, not much information about ACC and DEC demands in female soccer training was reported in the literature, therefore a major part of the studies reported in this review included male participants. Future research should investigate female soccer players' training demands. Third, future studies should investigate the ACC and DEC demands during training of specific roles, like floaters, because the knowledge regarding roles is currently very limited. Finally, as scarce evidence exists on goalkeepers ACC and DEC demands representing an important limitation, future studies should investigate their demands to offer a better understanding of goalkeepers training needs.

Conclusions

This review summarizes the current knowledge about ACC and DEC demands in soccer training. Since soccer drills can be adjusted according to different tactical and technical goals, different ACC and DEC demands can be expected. SSG is a training drill widely used in soccer training and elicits higher ACC and DEC demands than other training methods such as circuit training and running-based drills and its format can be modified to match specific objectives. SSG formats with few players and/or small pitch size tend to increase ACC and DEC demands and these demands can also differ for each playing position, for instance, central positions appear to be subject to fewer demands than players that play in wide positions. Considering the training week, ACC and DEC demands decrease as match day approaches and this strategy is frequently used in team sports to avoid pre-match fatigue and increase match preparedness. Moreover, ACC and DEC demands were greater during MD-4, MD-3, and MD+1C, while MD-1 was the least demanding. Lastly, this review found that the match represents the most demanding session of the week, therefore a compensatory session could be used to avoid under-loading non-starter players.

Practical Applications

Monitoring acceleration and deceleration demands during soccer training with arbitrary thresholds complicate comparisons between studies. Furthermore, the same arbitrary thresholds vary between intensity classification. Practitioners are therefore advised to individualize players' efforts.

Since SSG elicit higher demands than other training drills, practitioners should be careful when applying these drills, especially in smaller formats as they elicit higher demands than shorter formats. The correct drills choice can provide higher demands during the middle of the week and smaller demands near competition, facilitating proper recovery and preparedness for matches. Finally, the fact that wide positions may be exposed to higher demands than central defenders, should be reflected in recovery and compensation sessions strategies.

CHAPTER IV: SCIENTIFIC RESEARCH

SUBCHAPTER: EMPIRICAL STUDIES

4.3. Study III (Using minimum effort duration can compromise the analysis of acceleration and deceleration demands in soccer)

Citation: Silva H, Nakamura FY, Ribeiro J, Asian-Clemente J, Roriz P, Marcelino R. Using minimum effort duration can compromise the analysis of acceleration and deceleration demands in football. International Journal of Performance Analysis in Sport. 2023 Apr 14:1-3. DOI: 10.1080/24748668.2023.2201745

Abstract

The aim of this study was to characterize soccer players' accelerations and decelerations demands regarding duration, initial velocity, and efforts magnitude without a minimum effort duration. Forty-two male professional players were monitored daily during four training weeks, using global position system. Players were divided according to their playing positions as central defenders, fullbacks, central midfielders, wide midfielders, and forwards. Acceleration and deceleration efforts were analyzed from the start of the change of velocity until it stopped increasing (acceleration) or decreasing (deceleration). Descriptive statistics were performed for occurrences, initial velocities, and average and peak magnitudes. Comparisons between playing positions was conducted with one-way ANOVA. Occurrences of accelerations and decelerations decreased as the duration increased. The initial deceleration velocity increased with duration, but no changes were seen in the acceleration initial velocity. The average effort's magnitude increased with duration, while the peak magnitudes decreased showing acceleration and deceleration peaks between 0.5-1.3 and 0.1-0.3 seconds respectively. Differences between playing positions occurred between 0.7 and 2.5 seconds. In conclusion, the measurement of accelerations and decelerations should avoid the use of minimum effort duration since it can modify the real training load of soccer players.

Keywords: running, intensity, microcycle, soccer, speed

Introduction

Accelerations and decelerations are fundamental to success in team sports as the ability to rapidly change velocity allows players to respond to different stimuli found in during competition (184) . In soccer, players need to alternate activities every 4-6 seconds (120), several of them at high intensities (185), which affect the overall load imposed on players (186). Of note, players perform more maximal accelerations efforts than sprinting efforts during matches (187). The importance of accelerations and decelerations in soccer can increase even more in the future, due to tactical evolutions (6). It is therefore no surprise that these intense efforts are frequently monitored during matches and training sessions, with acceleration' variables being commonly used to monitor training and matches' external loads (3,188). In this regard, the number of studies reporting acceleration and deceleration data is increasing exponentially, especially in soccer (5). Increasingly, the role of deceleration in soccer has been highlighted because this effort can place underprepared players in higher injury risk (20). As so, it would be crucial for practitioners to evaluate if players are performing intense accelerations and decelerations during training, increasing their preparedness to competition demands.

Before reporting accelerations and decelerations data, it is important to decide how these efforts should be operationally defined. One frequently discussed topic refers to the minimum effort duration (MED), which establishes the minimum duration that the acceleration must exceed to be counted, using a specific velocity or acceleration threshold (17). For example, in a 0.5 MED, the acceleration needs to be sustained for at least half a second to be counted (13). However, using too short MED can be problematic because small changes as 0.1 seconds substantially affect the number of accelerations detected (17). Moreover, the chosen MED in scientific studies is generally arbitrary (13). Currently, there is no consensus on what MED to use as short MED (0.1-0.3) could capture short and discrete events with greater possibility to underestimate too closely accelerations and decelerations. Additionally, longer MED (> 0.5) can underestimate the number of efforts. (13). Taking into account that the GPS manufacturer can dictate the MED selection and some software allow customization (13) the selection of MED thresholds has become a concern for coaches.

Another important aspect of monitoring is to retrieve information regarding the initial velocity leading to an acceleration or deceleration as it can affect the mechanical loading of the action (24). That is, at what velocity is the player moving when he or she starts increasing or decreasing their speed. Sonderegger et al. investigated this issue in junior soccer players and reported a linear decrease in the maximal voluntary acceleration as the initial running velocity of the sprints increased (24). In the referred study, each athlete performed a running test starting at different velocities (standing start at 6.0, 10.8 and 15.0 $km.h^{-1}$) to reach the maximal voluntary acceleration and maximal running speed. De Hoyo et al. (175) applied this method in elite soccer matches and reported differences between playing positions: central defenders performed more accelerations starting with low initial velocities (0.0 to 7.0 $km·h^{-1}$), strikers and wide midfielders performed more accelerations starting at high velocities (> 14.4 $km·h^{-1}$), and fullbacks and midfielders combined accelerations starting at low and high initial velocities (midfielders performed more starting at low initial velocities).

Acceleration and deceleration monitoring is often performed with global positioning systems (GPS) (5,13). GPS is a navigation system that uses satellites in orbit around Earth and sends information (at the speed of light) to the GPS receiver (14,15). These devices can gather data at different sampling rates (16). For example, if one GPS has a sampling rate of 10Hz, 10 data points can be collected per second, and the higher the sampling rate, the more accurate measurements can be (16). However, a higher frequency can also result in noise, by classifying a single effort as two (or more) separate efforts (5,17). Velocity and acceleration efforts are usually calculated by measuring the change in frequency of the satellite emitted periodic signal (Doppler shift), which has shown a higher level of precision compared with positional calculations (14,15). The 10 Hz sampling rate GPS have been validated for assessing accelerations (184), but it appears that as the magnitude of the change in speed increases, the accuracy of the equipment decreases (13,189). Buchheit et al. (183) raised additional concerns, reporting variations in accelerations and decelerations measures between models and units from the same manufacturer.

Despite important findings obtained with the accelerations, this method has disregarded decelerations efforts, which are crucial in soccer activities (20). Quantifying decelerations is relevant because they are associated with high mechanical loading, fatigue, and muscle damage in team sports players (113). As so, studying the impact of initial velocities on decelerations would be at least as important as on accelerations efforts. Additionally, by using arbitrary MED's, short duration decelerations could be ignored from the load monitoring, which can place players at a higher injury risk.

Therefore, the aim of this study was to characterize accelerations and decelerations demands in soccer training regarding duration, initial velocity, and efforts magnitude, considering the different playing positions.

Methods

Procedure

Professional soccer players from two Portuguese teams that competed in the 1st division were monitored during training sessions for 4 consecutive in-season microcycles. Training sessions were planned and conducted by coaching staffs, without any alteration for research purposes. No specific acceleration or deceleration training was conducted during this study. Data was collected in the 2020/21 and 21/22 seasons (one team per season) to analyze accelerations and decelerations efforts without applying any minimum effort duration and considering the efforts initial velocities.

Subjects

An observational study was conducted on forty-two male professional players (mean ± SD: age: 27 ± 4 years, height: 182 ± 6 cm and body mass: 75 ± 6 kg) who were monitored daily during training sessions. Players were divided according to their playing positions by the coaching staffs as central defenders (CD), fullbacks (FB), central midfielders (CM), wide midfielders (WM) and forwards (FW). Goalkeepers were excluded from this study. Number of players and training files are presented in Table 10. Coaching staffs collected the data (being part of daily routine in which players are continually monitored throughout the season) and obtained permission from the respective authorities in clubs. The research was approved by the ethic committee of the University of Maia (35/2021).

Table 10. Sample characteristics (number of players and training files per playing position).

	CD	**FB**	**CM**	**WM**	**FW**	**Total**
Players (*n*)	8	10	13	6	5	42
Training files (*n*)	148	192	264	110	98	812

CD=central defender; FB=fullback; CM=central midfielder; WM=wide midfielder; FW=forward.

Acceleration and deceleration assessment

The teams monitored their players using a 10 Hz global positioning system (Catapult Vector S7 and Vector X7 – one model for each team – Catapult Sports, Melbourne, Australia) that encompassed a double constellation system (GNSS and GPS). Both models are FIFA certified (190). The 10 Hz sampling rate has also been validated for velocity measurements (45). Devices were secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use, in accordance with the manufacturer's instructions.

Raw data of training sessions were retrieved from the GPS software (OpenField Console, Catapult Sports, Melbourne, Australia) and the velocity ($m \cdot s^{-1}$) and time (milliseconds) were used to calculate accelerations and decelerations ($m \cdot s^{-2}$). The duration of accelerations was calculated by the difference between the end of the acceleration (when velocity stopped increasing) and the start of the acceleration (initial velocity) (13), using the same procedure for decelerations but when the velocity stopped decreasing.

Since potential data noise could arise due to equipment signal error caused by players being near a cover area (i.e. benches while drinking water), accelerations above 9.5 $m \cdot s^{-2}$ and running speeds above 44.45 $km \cdot h^{-1}$ were ignored (37,191); on the contrary, restrictions were not carried out in decelerations, avoiding the elimination of actions such as collisions or sudden stops. Maximal accelerations and decelerations were retrieved as the maximal individual value of each player when another effort was registered within 1 $m \cdot s^{-2}$ (for example, a maximal acceleration of 5.2 $m \cdot s^{-2}$ required another acceleration ≥ 4.2 $m \cdot s^{-2}$; the same procedure for decelerations). Additionally, data that represented less than 0.20% of efforts was ruled out which means that efforts with durations above 3 seconds were excluded. This procedure was selected to exclude individual values from data.

Accelerations and decelerations were exported to Microsoft Excel with time (seconds) and initial and final velocities ($km \cdot h^{-1}$) for each effort. For each player, the percentage of occurrences was calculated by the number of accelerations and decelerations in each duration interval (in 0.1 seconds intervals) in relation to the absolute number of efforts. Initial velocities ($km \cdot h^{-1}$) and acceleration and deceleration average and peak magnitudes ($m \cdot s^{-2}$) were calculated for each duration interval (0.1 seconds).

Statistical analysis

Descriptive statistics were performed for percentage of acceleration and deceleration occurrences, initial velocities, average and peak accelerations and deceleration magnitudes regarding each duration interval (0.1 seconds to 3.0 seconds) and for each playing position with means ± SD and calculated using Excel.

Differences between playing positions (CD, FB, CM, WM and FW) for percentage of occurrences, initial velocities and acceleration and deceleration magnitudes (averages and peaks) were analyze with one-way ANOVA, and means differences were calculated with Tukey post-hoc test, using jamovi (192,193). Statistical significance was established at $p < .05$.

Results

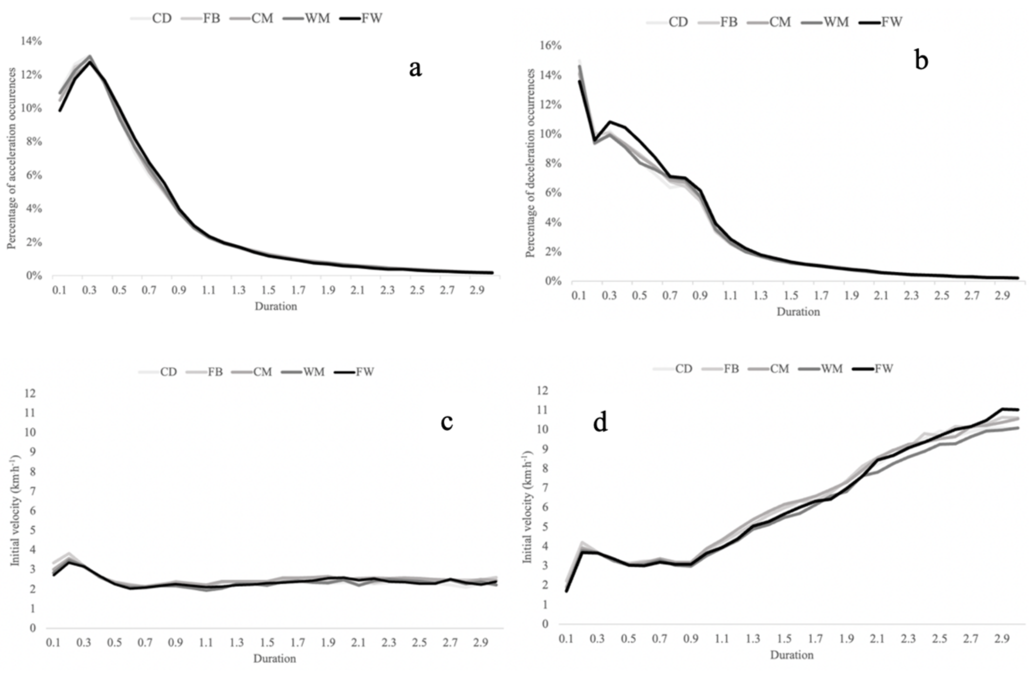

Figure 10. Accelerations and decelerations occurrences percentage (a and b, respectively) and efforts initial velocities (km·h^{-1}) (c and d, respectively) per duration interval and per playing position.

In total, we counted 98.76% of accelerations and 99.61% of decelerations efforts during this study (the missing efforts were longer than 3 seconds). These percentage of accelerations and decelerations occurred mostly in durations shorter than 1 second (83% of acceleration and deceleration total efforts). As seen in Figure 10 (a and b), all playing' positions have shown a tendency to perform less acceleration and deceleration efforts as the duration increased. In all playing positions, acceleration initial velocities sustained a fairly constant velocity (between 2 and 4 $km \cdot h^{-1}$) across all duration's intervals, while decelerations initial velocities increased as the duration of the effort increased (Figure 10, c and d).

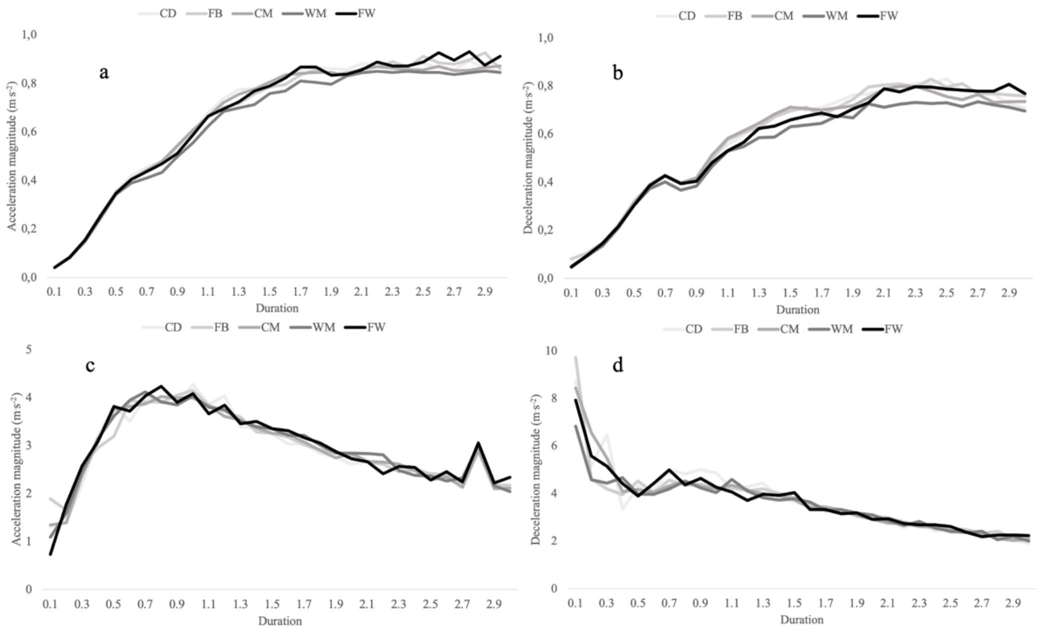

Figure 11. Efforts magnitudes per duration interval as position average and peak acceleration magnitudes ($m \cdot s^{-2}$) (a and c, respectively) and average and peak deceleration magnitudes ($m \cdot s^{-2}$) (b and d, respectively).

In Figure 11, acceleration and deceleration magnitudes are presented as the average (a and b) and the peak (c and d) values for each duration interval. The average magnitude increased with duration for all positions and for both acceleration and deceleration efforts. The peak acceleration magnitude was mostly achieved between 0.7 and 0.9 duration intervals for all playing' positions while the peak deceleration magnitude was mostly achieved in the first duration intervals (0.1 and 0.2) for all playing positions.

Table 11. Statistically significant mean differences (Tukey post-hoc test) and mean ± SD between playing positions for each variable (percentage of occurrences, initial velocities, average efforts magnitude and peak efforts magnitude) and accounting for each duration interval (from 0.1 to 3.0 seconds).

Variable	Duration Interval (seconds)	Positions	Mean Difference	Mean ±SD
Percentage of acceleration occurrences	0.7	CD and FW	-0.782*	5.96±0.43 vs. 6.75±0.56
	0.8	CD and FW	-0.611**	4.91±0.37 vs. 5.52±0.27
		FB and FW	-0.557**	4.96±0.20 vs. 5.52±0.27
		CM and FW	-0.515*	5.01±0.32 vs. 5.52±0.27
Percentage of deceleration occurrences	1.0	FB and FW	-0.553*	3.35±0.16 vs. 3.91±0.74
Acceleration initial velocities	1.1	CM and WM	0.290*	2.22±0.22 vs. 1.93±0.13
	1.2	FB and WM	0.304*	2.34±0.21 vs. 2.04±0.08
		CM and WM	0.346**	2.38±0.21 vs. 2.04±0.08
Deceleration initial velocities	1.0	CM and WM	0.374*	3.88±0.25 vs. 3.51±0.18
	1.2	CM and WM	0.561*	4.87±0.29 vs. 4.31±0.30
	1.4	CM and WM	0.662*	5.79±0.37 vs. 5.13±0.39
	1.5	CM and WM	0.677*	6.17±0.28 vs. 5.49±0.40
	2.4	FB and WM	0.914*	9.69±1.06 vs. 8.88±0.54
Acceleration average magnitudes	2.5	FB and CM	0.057*	0.91±0.05 vs. 0.86±0.33
Deceleration average magnitudes	1.4	CM and WM	0.095*	0.68±0.04 vs. 0.59±0.04
	1.9	CD and WM	0.094*	0.76±0.05 vs. 0.67±0.05
		FB and WM	0.100*	0.74±0.07 vs. 0.67±0.05
	2.6	FB and WM	0.095*	0.81±0.08 vs. 0.72±0.06
Acceleration peak magnitudes	2.2	CM and FW	0.245*	2.61±0.13 vs. 2.41±0.18
		WM and FW	0.392**	2.80±0.13 vs. 2.41±0.18

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. CD=central defender; FB=fullback; CM=central midfielder; WM=wide midfielder; FW=forward.

Statistically significant differences were found in acceleration occurrences (in 0.1, 0.8 and 2.2 duration intervals), acceleration initial velocities (in 1.1 and 1.2 intervals), deceleration initial velocities (in 1.0, 1.1, 1.2, 1.4, 1.5 and 2.9 intervals), acceleration average magnitudes (in 1.9 interval), deceleration average magnitude (in 1.4, 2.2, 2.3, 2.4, 2.6, 2.9 and 3.0 intervals), peak acceleration magnitude (in 2.2 interval) and peak deceleration magnitude (in 2.8 interval). Additionally, mean differences between playing positions were analyzed and out of 2400 possible paired comparisons, 20 achieved the significance level (< .05) (Table 11). These differences report that FW performed more acceleration efforts than CD in the 0.7 interval, CD, FB and CM in the 0.8 interval, and more deceleration efforts than FB in the 1.0 interval; WM had lower initial acceleration velocities than CM (1.1 interval), FB and CM (1.2 interval), and lower initial deceleration velocities than CM (1.0, 1.2, 1.4 and 1.5 intervals), an than FB (2.4 interval); FB had higher average acceleration magnitudes than CM in the 2.5 interval; WM had lower average deceleration magnitudes than CM (1.4 interval), CD (1.9 interval) and FB (1.9 and 2.6 intervals); and finally, FW had lower peak acceleration magnitudes than CM and WM in the 2.2 interval.

Discussion

The aim of this study was to characterize accelerations and decelerations demands in soccer training regarding duration, initial velocity, and efforts magnitude, and considering the different playing positions, without applying any minimum effort duration (MED). We found that using a MED could exclude several efforts, providing misleading information of players' training load. Acceleration initial velocity was fairly constant across different durations, while the deceleration initial velocity increased with duration. Efforts average magnitudes increased with duration and peak values were achieved between 0.7 and 0.9 duration intervals for acceleration, and 0.1 and 0.2 duration intervals for deceleration.

In our study, most accelerations and decelerations had durations inferior to one second. This is relevant since the frequent approach in scientific research is to use an arbitrary MED (13). Therefore, and considering our data, if we had chosen an MED of 0.2 or 0.3 seconds - MEDs frequently used in 10 Hz GPS (14) - only 36% of accelerations and 34% of decelerations would be reported with our sample. As so, by selecting a specific MED, half of accelerations and decelerations performed by players could have been ignored, which means that coaches could be making decision with misleading data. This finding is in line with previous research that highlighted that small changes in MED, such as 0.1 seconds, significantly affect the detected number of accelerations (17). As so, accelerations and decelerations should be counted until the rate of these movements reach $0\ m{\cdot}s^{-2}$ (13).

Our results showed that accelerations and decelerations initial velocity differ according to the initial velocity, with accelerations remaining fairly constant across the different effort's durations. Sonderegger and colleagues highlighted the importance of initial velocity stating that it should be accounted for when classifying accelerations intensities (24). These authors proposed that initial velocities should be fitted above three intervals trotting ($6.0\ km{\cdot}h^{-1}$), jogging ($10.8\ km{\cdot}h^{-1}$), and running ($15.0\ km{\cdot}h^{-1}$) and reported a linear decrease in maximal voluntary acceleration when sprints were initiated from increasing initial running speed. This approach was applied by other authors, reporting more high intensity accelerations starting in the running interval (175) and from static or walking speed (23). Instead of applying specific initial velocities thresholds, we reported the average initial velocities for each duration interval. With this strategy, we included all starting velocities, and found that the starting velocity of accelerations ranged from 2 to 4 $km{\cdot}h^{-1}$ for all durations intervals. As so, efforts starting at higher velocities would probably occur less often, as suggested by Varley and Aughey study in Australian football players (187). Additionally, we have also analyzed the initial velocities in deceleration efforts, which did not happen on the Sonderegger approach because intensities were calculated using the maximal voluntary acceleration, obtained by testing the players in linear sprints. In our study, we have found that decelerations' initial velocities increased as the effort duration increased, mainly ranging from 2 to 12 $km{\cdot}h^{-1}$. Interestingly, decelerations with very short durations and starting at a very high velocities, usually associated with injuries due to collisions or the fast increase in joints load (20), may be rare considering our findings. Despite this potential rarity, decelerations should be accounted for when analyzing demands imposed to soccer players, especially considering the importance of these efforts in injuries, muscle soreness and match demands (188).

Thirdly, acceleration and deceleration average magnitudes ($m{\cdot}s^{-2}$) increased as the duration of the effort increased as well. Since an effort would be more intense if a higher velocity is achieved in less time, we could expect to see magnitudes decreasing as the duration increased. However, we should keep in mind that the analyzed effort duration is equal or shorter than 3 seconds, which can be considered as a short time. With our findings, an important reflection can emerge relative to how accelerations and decelerations are usually assessed in soccer: as number of efforts or distance covered accelerating and decelerating (194). However, a player can perform a high number of accelerations or decelerations in shorter distances, or lower number of efforts in longer distances. Either case, the time spent accelerating or decelerating is a major factor to consider during training monitoring. Considering our findings, we could extrapolate that if the efforts' magnitude increases with duration, that would mean that during efforts with higher magnitudes players would cover higher distances. For example, accelerations of 4 $m{\cdot}s^{-2}$ for 1 or 2 seconds would add 2 or 8 meters respectively [$\Delta x = v_0 t + (1/2)at^2$] to the total distance covered. This was showed by Pons and colleagues (195) when comparing number and distance covered in different acceleration and deceleration thresholds (0-1, 1-2, 2-3 and > 3 $m{\cdot}s^{-2}$) registered by a video tracking system and a GPS device during competition. Although the authors did not compare the number of efforts with the distance covered, their descriptive statistics affirmed that the distance covered per number of efforts increased as the magnitude increased as well.

However, since we analyzed the average magnitude of accelerations and decelerations, and since there were fewer efforts in longer durations, an explosive effort would be more represented in these longer intervals. However, after analyzing the peak magnitudes ($m{\cdot}s^{-2}$), we found that peak accelerations magnitudes were higher (around 4 $m{\cdot}s^{-2}$) with durations of 0.5-1.3 seconds, while peak decelerations (between 7-10 $m{\cdot}s^{-2}$) lasted 0.1 and 0.2 seconds. This finding clearly reveals the potential prejudice of using an arbitrary MED, by excluding very intense efforts. Higher acceleration values in shorter time windows were also reported when assessing maximal acceleration through a maximal 20 meters sprint (119). Moreover, an arbitrary MED would exclude very intense decelerations, which can place players at higher injury risk, especially if not accustomed to these efforts' intensities (20). Unfortunately, measurements of maximal accelerations and decelerations in real contexts (training or matches) are rare or do not provide the absolute values (196). Sannincandro and colleagues (138) compared different small-sided games variations (2 GK + 6 external wildcards in 5 vs. 5, 6 vs. 6 and 7 vs. 7 formats) and reported maximal accelerations and decelerations of 3.88 $m{\cdot}s^{-2}$ and 4.68 $m{\cdot}s^{-2}$ respectively as average values of the study sample. However, it is not clear if these values were retrieved from raw data or after the software filter. On the other hand during a sprint and a 12 meters change of direction Gaudino et al. reported maximal acceleration and deceleration values of 7.05 and 8.00 m.s-2 respectively (197). This means that players can achieve high magnitude efforts, but these higher values can potentially be filtered before practitioners and researchers report their data. We should also highlight the peak acceleration magnitude in the 2.7-2.9 duration intervals (Figure 11c). The sudden increased in values was analyzed and happened in both teams for all players, but the highest increase obtained was 0.81 $m{\cdot}s^{-2}$ (forwards).

Finally, we have found differences between playing' positions in specific variables and specific duration intervals. Due to the novelty of this analysis, it is difficult to compare our finding with other research results. One finding from our data is that all significant differences occur between 0.7 and 2.5 duration intervals. This could mean that in shorter actions (< 0.7 seconds), all playing positions can be subject to similar acceleration and deceleration training demands. Another interesting finding is the lower acceleration and deceleration initial velocities of WM (except to CD – no significant difference), since higher demands appear to be imposed to wider positions (194). Moreover, higher values were reported for WM considering maximum acceleration and maximum running speed in matches (198,199). Likewise, Di Salvo et al. (200) reported higher distances covered in matches by WM than the other positions in velocities > 19 $km \cdot h^{-1}$, and smaller distances covered by WM - except than FW - in velocities < 11 $km \cdot h^{-1}$; Akenhead et al. (26) reported similar results in soccer training. As so, since WM cover higher distances in high velocities and perform more acceleration and deceleration efforts, but cover lower total distances, we can suggest that these high intensity efforts are performed in shorter durations (< 1 second).

Despite novel results obtained in this study some limitations should be considered. First, these data relate to a specific context, the Portuguese first division, and different results can be found in a different one. Here, and regarding potential comcerns of considering two different GPS models (but same brand), we present the comparison between teams, illustrating a similar trend (Figures 12-14). Second, by averaging velocities, we can undervalue very intense efforts, even if they occur rarely. However, we should highlight that creating a visual and practical image of these findings by using millions of data points is extremely difficult. Additionally, by avoiding any MED filter, we may include very low intensity efforts, that translate in small variations of velocity. Nevertheless, these potentially irrelevant efforts could be filtered without simultaneously excluding intense and short efforts, if one filter is created for the intensity or magnitude. Finally, no match data was considered, but since this study provides a novel approach to this topic, fewer variables can facilitate the data interpretation. Future studies should analyze different samples or contexts such as matches and training variables.

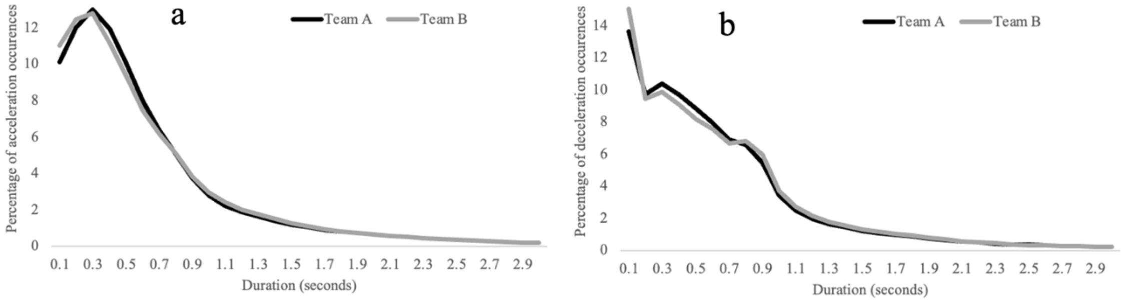

Figure 12. Percentage of occurrences of accelerations (a) and decelerations (b) per duration interval and per team.

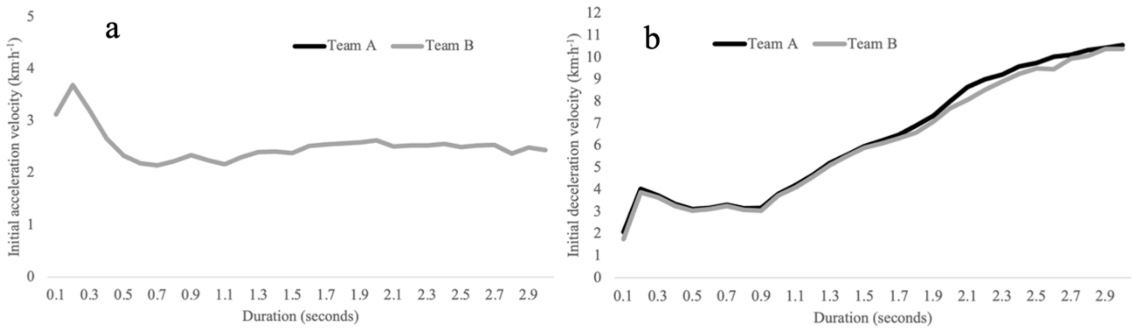

Figure 13. Percentage of occurrences of accelerations (a) and decelerations (b) per duration interval and per team.

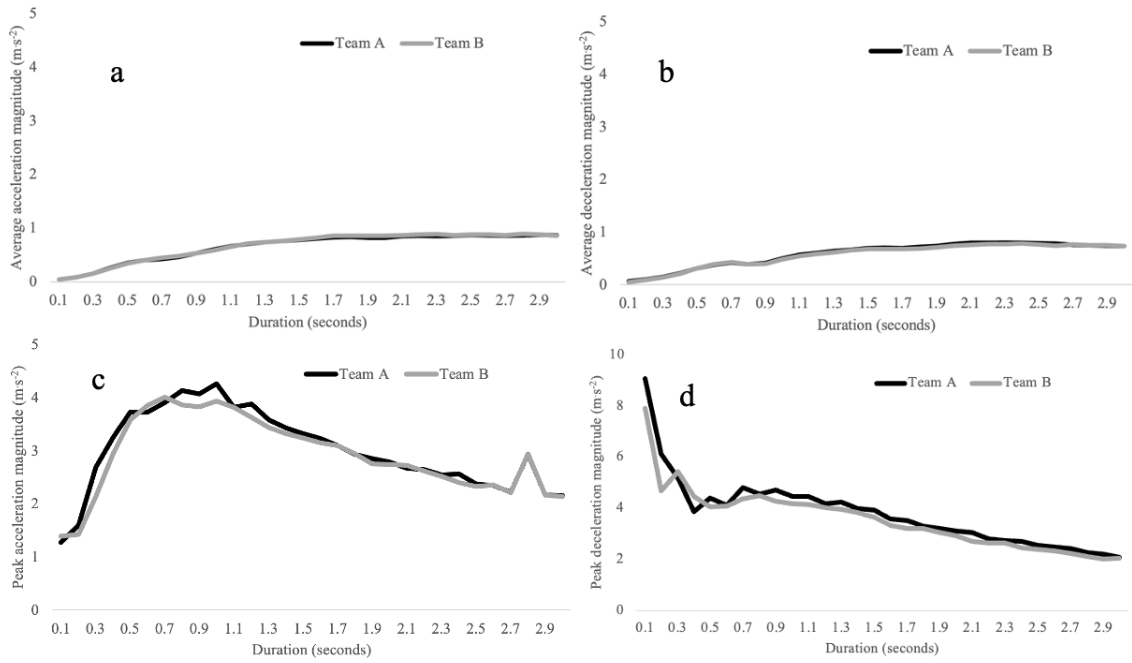

Figure 14. Efforts magnitudes per duration interval and per team as average and peak acceleration magnitudes (a and c, respectively) and average and peak deceleration magnitudes (b and d, respectively).

Monitoring accelerations and decelerations with MED can mislead coaches relative to the real player's training load. These efforts occur in different duration intervals and initial velocities and magnitudes of those efforts can differ between each interval. Shorter durations are usually excluded from these measurements but were where most efforts occur and where we found higher acceleration and deceleration peak magnitudes.

Conclusions

The measurement of accelerations and decelerations should avoid the use of MED as it can exclude several efforts modifying the real training load of soccer players. As so, these efforts should be assessed from the start of the increase or decrease in velocity until the change in velocity reaches 0 $m \cdot s^{-2}$. With this method, we can see a decrease in accelerations and decelerations as the effort’s duration increased. Regarding the initial velocity of these efforts, as the initial velocity of accelerations remained fairly the same across different durations, the initial deceleration velocity increased with duration. The average effort’s magnitudes increased with duration, while the peak magnitudes decreased. The acceleration and deceleration peaks occurred between 0.5-1.3 and 0.1-0.3 respectively. Finally, differences between playing positions occurred between 0.7 and 2.5 duration intervals, and this could mean that similar demands can be seen in shorter intervals.

Practical Applications

Using minimum effort duration can compromise the report of true training load, especially considering that decelerations with high magnitudes (> 6 $m \cdot s^{-2}$) have short durations (< 0.3 s). As so, practitioners are advised to assess accelerations and decelerations without establishing an (arbitrary) minimum effort duration. Even if this strategy could potentially consider insignificant efforts (with very low magnitudes), data can be subsequently filter with intensity thresholds (absolute or relative). With this adaptation, these potential insignificant efforts (such as efforts < 0.1 $m \cdot s^{-2}$) would be excluded, while maintaining high-intensity decelerations.

4.4. Study IV (Adapting the percentage intensity method to assess accelerations and decelerations in soccer training: moving beyond absolute and arbitrary thresholds)

Citation: Silva H, Nakamura F, Serpiello F, Ribeiro J, Roriz P, Marcelino R. Adapting the percentage intensity method to assess accelerations and decelerations in football training: moving beyond absolute and arbitrary thresholds. (PrePrint). DOI: 10.51224/SRXIV.286

Abstract

We present an adaptation of the percentage intensity approach to monitor accelerations and decelerations allowing players' individualization. Forty-two players were monitored during four training weeks via GNSS devices. Raw velocity and time data were collected, allowing acceleration, deceleration, and starting speed calculations. Training maximal accelerations and decelerations were calculated for each starting speed interval, and intensities were established as very low (< 25% of the maximal effort), low (25-50%), moderate (50-75%) and high (> 75%). Linear regressions and Pearson correlation (*r*) analyzed the relationship between the maximal acceleration and deceleration according to starting speeds, and mean paired differences compared efforts magnitudes between starting speed intervals. Most very-low intensity efforts started < 5 $km \cdot h^{-1}$ (79-86%). Correlation between maximal efforts and starting speeds were -0.97 (p<.001) and -0.94 (p<.01) respectively. Maximal acceleration decreased as starting speed increases (very large effect sizes), but deceleration is less starting speed dependent (unclear to large effect sizes) during training. This adaptation allows individual accelerations and decelerations classification during real-life scenarios, which can lead to a more precise training prescription. Very low intensity could be excluded to consider only relevant efforts. Maximal acceleration should be collected for each starting speed interval because accelerations are starting speed dependents.

Keywords: soccer, threshold, training, velocity.

Introduction

During soccer training sessions and matches, practitioners monitor load to assess if players are meeting physical demands requirements and responding to the stimulus provided (57,58). Different tools can assess load, including heart rate and perception of effort (i.e., internal load), or variables obtained via global navigation satellite system (GNSS) (57), such as the distance covered, the efforts performed at a specific velocity, or acceleration and deceleration occurrences (i.e., external load).

The quantification of accelerations and decelerations has become widely popular and these variables are among the most used metrics in elite soccer (3). This comes as no surprise since high-intensity accelerations are typically associated with fatigue and exercise-induced muscle damage (79) with implications for post-match recovery (113).

When collecting these data, efforts count is the most-commonly used approach, followed by the distance covered accelerating or decelerating (13). Scientific literature-based values can be very practical to use but raise two important concerns: the justification of the chosen categories and the "one size fits all" approach. Different "round-figure" thresholds are used in the literature but, since there is no justification to choose a specific threshold, researchers usually adopt values in the past (19,20). Additionally, intensity classifications vary across studies, making comparisons difficult (194). For example, high-intensity accelerations ranged from 2-3 $m \cdot s^{-2}$, to > 2.5 $m \cdot s^{-2}$, > 3 $m \cdot s^{-2}$ and > 4 $m \cdot s^{-2}$ across studies (194). Additionally, those strategies disregard individual capacities. If "high-intensity" is defined arbitrarily, a high-intensity action for one player could be of low- or moderate-intensity for another (23). To address this issue, Abbot and colleagues (162) compared an absolute intensity method with a relative intensity method during training sessions and friendly matches, reporting higher distances covered in the absolute intensity method. This means that results are influenced by the chosen method to classify accelerations and decelerations.

Additionally, Sonderegger and colleagues (24) highlighted the importance of the effort starting speed, proposing the acceleration intensity calculation as the percentage of the maximal observed acceleration and the maximal voluntary acceleration that could be achieved for each starting velocity [standing start; trotting (6.0 $km \cdot h^{-1}$), jogging (10.8 $km \cdot h^{-1}$), and running (15.0 $km \cdot h^{-1}$)]. Then, intensity was classified as high (acceleration >75% of the maximal), moderate (>50%), low (>25%), and very low (<25%). During matches, similar approaches have been used by different research groups to assess accelerations (23,162,175,201), with conflicting results. However, the cited papers used different starting speed thresholds and did not use the four relative acceleration intensity intervals previously proposed. Of note, for this method, maximal acceleration was assessed during four acceleration tests, and assessing maximal acceleration as originally proposed could not be practical during the competitive season (175). Also of note, decelerations were disregarded in the original proposal (24), which is an important limitation due to the importance of these actions in soccer practices (9).

Therefore, with this study, we aim to provide a new method to classify accelerations and decelerations intensities during soccer training, by adapting the previous published individual percentage intensity method. We hypothesized that acceleration magnitudes would decrease with starting speed increases, and deceleration magnitudes would increase with starting speed increases.

Methods

Procedures

Forty-two male professional soccer players from two Portuguese teams competing in the first division were monitored during one full mesocycle (4 weeks). Data were collected in the 2020/21 and 21/22 seasons (one team per season).

Subjects

Coaching staff monitored and collected the daily training data from forty-two male professional players. To be included in this study, a minimum of 50% participation in training sessions was required. The average age, height and weight were 26.7 ± 4.2 years, 181.7 ± 6.3 cm, and 74.5 ± 6.0 kg. Due to the particularities of the position, goalkeepers were excluded from data collection. Sample characteristics are presented in Table 12. Since players monitoring was part of their professional routine, Ethics Committee clearance was not required (48), but written consent from the clubs was obtained.

Table 12. Sample characteristics as number of players, training files and average training sessions attendances (mean ± SD) per playing position.

	CD	FB	CM	WM	FW	Total
Players (*n*)	8	10	13	6	5	42
Training files (*n*)	148	192	264	110	98	812
Percentage of training sessions attendance (mean ± SD)	84.48 ± 12.25	89.08 ± 8.85	92.31 ± 7.37	84.58 ± 6.59	90.33 ± 10.26	88.71 ± 9.64

Note: CD=central defender; FB=fullback; CM=central midfielder; WM=wide midfielder; FW=forward.

Acceleration and deceleration assessment

The teams monitored their players using a 10-Hz global positioning system (Catapult Vector S7 and Vector X7 – one model per team – Catapult Sports, Melbourne, Australia) that encompassed a double constellation system (GNSS and GPS). Both models are FIFA certified (190) and the 10-Hz sampling rate has been validated to assess accelerations in team-sports (45). Devices were secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use, in accordance with the manufacturer's instructions.

Raw data of training sessions were retrieved from the proprietary software (OpenField Console, Catapult Sports, Melbourne, Australia) and the velocity ($m{\cdot}s^{-1}$) and time (ms) were used to calculate accelerations and decelerations ($m{\cdot}s^{-2}$). Training maximal accelerations and decelerations were retrieved as the maximal individual value when another effort was registered within 1 $m{\cdot}s^{-2}$ (for example, a maximal acceleration of 5.2 $m{\cdot}s^{-2}$ required another acceleration ≥ 4.2 $m{\cdot}s^{-2}$; the same procedure for decelerations). Training procedures were conducted as usual with no interference from the research team.

Thresholds and Intensities

Players' acceleration and deceleration efforts from training sessions were retrieved with the starting speed ($km{\cdot}h^{-1}$) and the effort magnitude ($m{\cdot}s^{-2}$). The starting speed was retrieved as the registered speed immediately before the speed increase (acceleration) or decrease (deceleration). Accelerations and decelerations were calculated as the change of speed divided by the change of time – as long as speed kept increasing or decreasing, one effort was counted. As so, no minimum effort duration was applied to ensure that all efforts were accounted (13).

For the percentage intensity calculation, we adapted the Sonderegger et al. proposal (24), using the following equation to calculate percentage acceleration:

$$\text{Percentage acceleration} = \frac{\text{amax, action}}{\text{amax}} * 100$$

Where "amax, action" corresponds to the action acceleration or deceleration (each individual effort) according to the starting speed bandwidth interval (<5 $km{\cdot}h^{-1}$, 5-10 $km{\cdot}h^{-1}$, 10-15 $km{\cdot}h^{-1}$, 15-20 $km{\cdot}h^{-1}$, 20-25 $km{\cdot}h^{-1}$, 25-30 $km{\cdot}h^{-1}$ and > 30 $km{\cdot}h^{-1}$); and "amax" corresponds to the maximal acceleration or deceleration achieved during training for each starting speed bandwidth interval (< 5 $km{\cdot}h^{-1}$, 5-10 $km{\cdot}h^{-1}$, 10-15 $km{\cdot}h^{-1}$, 15-20 $km{\cdot}h^{-}$1, 20-25 $km{\cdot}h^{-1}$, 25-30 $km{\cdot}h^{-1}$ and > 30 $km{\cdot}h^{-1}$).

Accelerations and decelerations intensities were categorized as high (>75%), moderate (25-50%), low (25-50%), and very low (<25%).

Statistical analysis

Descriptive statistics were conducted to analyze efforts intensities and starting speeds. Accelerations and decelerations occurrences were analyzed as a percentage of all occurrences. Linear regressions and Pearson correlation (*r*) were calculated to analyze the relationship between the maximal acceleration and decelerations and starting speeds, using jamovi (192,193). Mean paired differences compared accelerations and decelerations magnitudes between subsequent starting speed intervals, in jamovi with the ESCI package (192,193). Cohen's (*d*) effect sizes were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). If the CI crossed zero, an unclear effect size was established (55).

Results

Most of very low intensity accelerations and decelerations started from < 5 km·h⁻¹ (86% and 79% respectively). Similarly, most of low and moderate intensity accelerations started from < 5 km·h^{-1} (79% and 68% respectively), while most of low and moderate intensity decelerations started between 5-15 km·h^{-1} (66% and 61% respectively). High-intensity accelerations started mainly < 10 km·h^{-1} (70%), while high-intensity decelerations varied from starting speeds of 15-20 km·h^{-1} (19%), 5-10 km·h^{-1} (19%), and 10-15 km·h^{-1} (31%). This is represented in Figure 15.

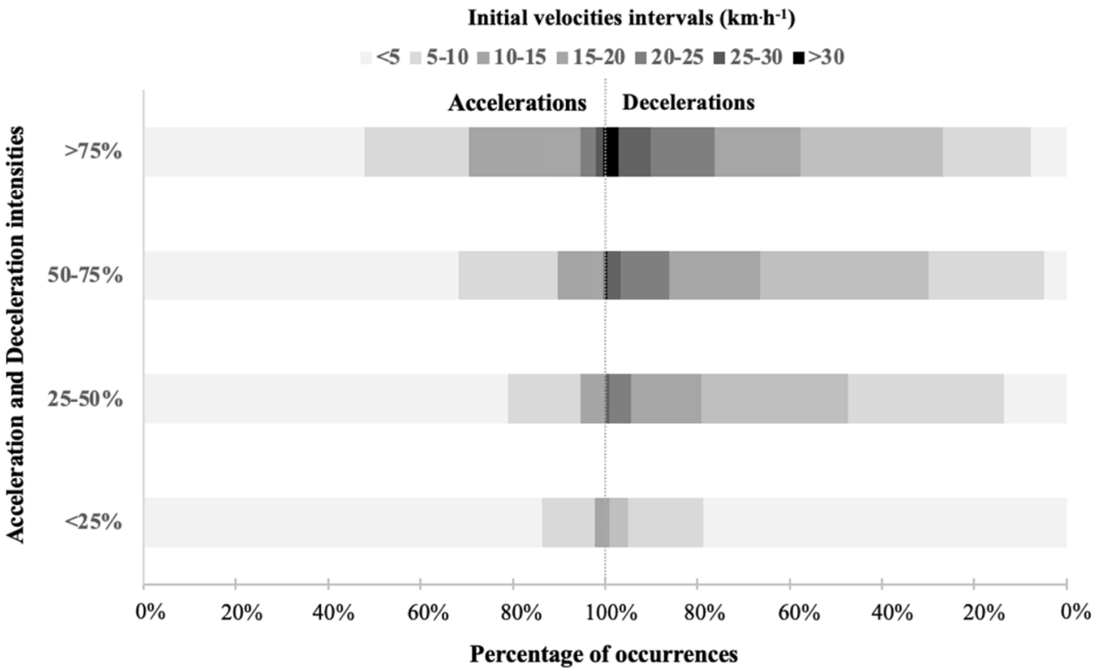

Figure 15. Comparison of mean percentage of accelerations and decelerations occurrences per training session separated per intensity interval, and according to initial velocity.

Means ±SD of maximal and average accelerations and decelerations per starting speed interval are presented in Table 13.

Table 13. Mean ± SD of maximal and average accelerations and decelerations for each bandwidth interval starting speed.

Starting Speed Interval ($km \cdot h^{-1}$)	Maximal Acceleration ($m \cdot s^{-2}$)	Maximal Deceleration ($m \cdot s^{-2}$)	Average Acceleration ($m \cdot s^{-2}$)	Average Deceleration ($m \cdot s^{-2}$)
<5	4.52 ± 0.66	6.08 ± 2.93	0.36 ± 0.46	0.23 ± 0.26
5-10	3.11 ± 0.31	5.44 ± 3.34	0.29 ± 0.41	0.43 ± 0.54
10-15	2.10 ± 0.28	4.64 ± 0.66	0.29 ± 0.35	0.89 ± 0.78
15-20	1.43 ± 0.25	5.00 ± 0.96	0.31 ± 0.31	1.36 ± 0.88
20-25	0.80 ± 0.24	4.41 ± 0.79	0.24 ± 0.22	1.61 ± 0.92
25-30	0.45 ± 0.26	3.56 ± 0.72	0.23 ± 0.22	1.72 ± 0.88
>30	0.14 ± 0.07	2.24 ± 0.66	0.14 ± 0.06	1.63 ± 0.65

Correlation between maximal accelerations and decelerations were -0.97 ($p<.001$) and -0.94 ($p<.01$) respectively. Linear regressions and respective equations are presented in Figure 16.

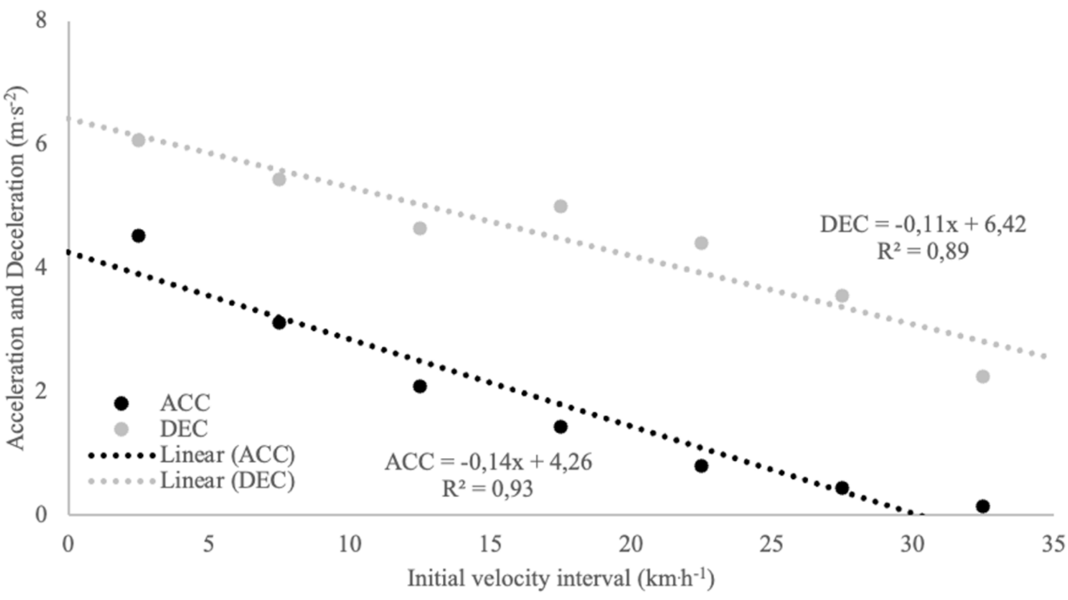

Figure 16. Linear regression of maximal accelerations (ACC) and decelerations (DEC) for each initial velocity bandwidth (< 5 $km \cdot h^{-1}$, 5-10 $km \cdot h^{-1}$, 10-15 $km \cdot h^{-1}$, 15-20 $km \cdot h^{-1}$, 20-25 $km \cdot h^{-1}$, 25-30 $km \cdot h^{-1}$ and > 30 $km \cdot h^{-1}$) for all players (n = 42).

As starting speed increased, differences in maximal accelerations decrease with very large effect sizes. The only exception was when comparing 20-25 km·h^{-1} with 25-30 km·h^{-1} starting speed intervals (large effect size). Maximal decelerations decrease between starting speed intervals, except between <5 km·h^{-1} and 5-10 km·h^{-1} (unclear), and between 10-15 km·h^{-1} and 15-20 km·h^{-1} (maximal decelerations increased with a small effect size). These differences are represented in Figure 17 (data available in Table S1 of Supplementary Information).

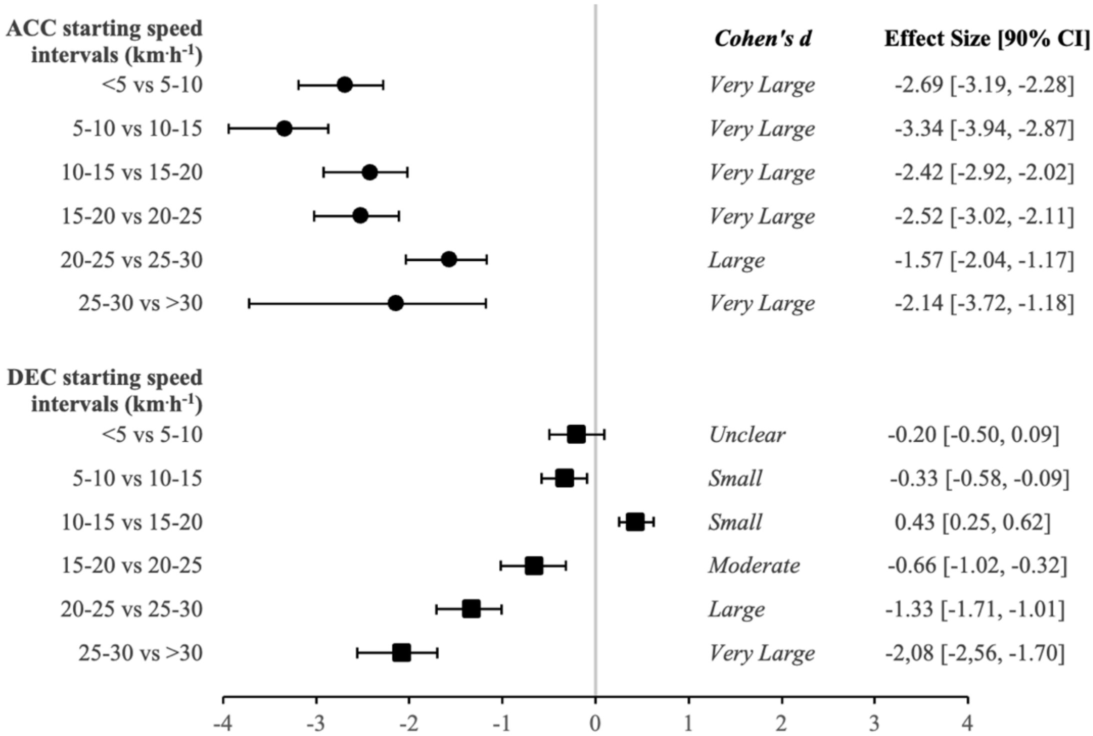

Figure 17. Differences between starting speed intervals (Cohen's d) for maximal accelerations (ACC) and decelerations (DEC).

Discussion

The main purpose of this study was to provide a new method to classify acceleration and deceleration intensities during soccer training, by adapting the individual percentage intensity method proposed by Sonderegger and colleagues (24) applied with sprint tests. We presented a practical method that allows practitioners and researchers to classify players' individual accelerations and decelerations efforts during training sessions and that could be potentially extended to competitive matches. Importantly, since we used maximal efforts as the highest values obtained during training sessions (per starting speed bandwidth interval), absolute players' capacities could differ if tested. However, field tests can only provide a glimpse of players' status, as players change their capacities across the season and constant testing is difficult to implement in elite contexts (202). Additionally, these tests are usually performed with a standing start which differs from what happens in competition and training practice. Nevertheless, previous research established the diminish capacity of accelerating as the starting speed increases (24), which relates with our findings. Regarding decelerations maximal capacities, one would expect that the higher magnitudes would be achieved when starting at higher speeds. Indeed, when assessing maximal decelerations with a field test, players were instructed to sprint maximally for 20 meters before decelerating (203). However, according to our findings, players appear to protect themselves during training, minimizing deceleration forces especially when running at higher velocities. That is, considering the potential damage of decelerations (9), players can voluntarily avoid sudden stops during practice. When comparing maximal decelerations magnitudes, our values ranged from 6 to 3 $m{\cdot}s^{-2}$, while previous research reported maximal decelerations 8 $m{\cdot}s^{-2}$ after achieving ~26 $km{\cdot}h^{-1}$ (203). As so, during training, players could minimize explosive decelerations when sprinting, even though the capacity to do so exists, with the associated risks (9). Nevertheless, this "protection" defines the training maximal decelerations and respective intensities for each player.

Accelerations and decelerations intensities are frequently classified with arbitrary thresholds that lack individualization (19,194). Additionally, they also ignore the efforts starting speed. Two studies compared this arbitrary classification with an individualize classification. First, Abbot and colleagues (162) compared a global method (low intensity: 1-2 $m{\cdot}s^{-2}$; moderate intensity: 2-3 $m{\cdot}s^{-2}$; and high intensity: > 3 $m{\cdot}s^{-2}$) with an individualize method during training sessions and friendly matches (low intensity: 25-50%; moderate intensity: 50-75%; and high intensity: > 75%) and calculated the maximum acceleration with players' testing. Players were then divided in groups according to their acceleration capacity (low, medium, and high). The authors reported higher distances covered in the global method (medium group: moderate and high intensity accelerations; and high group: all intensities). Hence, how practitioners classify players accelerations and decelerations impacts the load reported. The second study (204) compared the percentage intensity method (24) with a speed-based method (measured the distance cover in different speed zones: standing, 0.0-0.7 $km{\cdot}h^{-1}$; walking, 0.7-7.2 $km{\cdot}h^{-1}$; jogging, 7.2-14.4 $km{\cdot}h^{-1}$; running, 14.4-19.8 $km{\cdot}h^{-1}$; high-speed running, 19.8-25.2 $km{\cdot}h^{-1}$; and sprinting, > 25.2 $km{\cdot}h^{-1}$) and with an absolute method (low intensity: 1-2 $m{\cdot}s^{-2}$; moderate intensity: 2-3 $m{\cdot}s^{-2}$; high intensity: > 3 $m{\cdot}s^{-2}$; and another high intensity interval: > 4 $m{\cdot}s^{-2}$). However, the absolute threshold method was also dependent from initial velocity and the statistical analyzes focused in the sample level. From the latter study, differences were reported between methods, but similarities can be found in this study such as the number of efforts in > 75% and > 4 $m{\cdot}s^{-2}$ (29.7 vs. 30.7) intervals with starting speeds of 0-1 $m{\cdot}s^{-1}$. Finally, the latter study used open ended thresholds (>3 $m{\cdot}s^{-2}$ and > 4 $m{\cdot}s^{-2}$), which leads to the inclusion of different thresholds in the same interval (17).

We found that most of the very low intensity (< 25%) efforts started from < 5 $km{\cdot}h^{-1}$ (Figure 15) which means that these efforts probably represent insignificant changes of velocity and would probably relate to efforts < 1 $m{\cdot}s^{-2}$, which are often disregarded when assessing efforts with fixed thresholds (194). However, an acceleration of < 1 $m{\cdot}s^{-2}$ could represent a high intensity effort if starting > 25 $km{\cdot}h^{-1}$, because acceleration capacity decreases as starting speed decreases (Figure 16) (24). By considering the starting speed, we can recommend practitioners to disregard this intensity interval (< 25%) because they probably represent a negligible mechanical load to the player and can carry movement "artifacts". Additionally, we also recommend merging the starting speed intervals of 25-30 $km{\cdot}h^{-1}$ and > 30 $km{\cdot}h^{-1}$ to > 25 $km{\cdot}h^{-1}$, because very few efforts occur in the highest interval, which can condition maximal values.

To calculate the maximal acceleration and deceleration, we must consider the differences between the two efforts: while both maximal efforts tend to decrease as the starting speed increases (Figure 16), the acceleration capacity is more starting speed dependent than the deceleration capacity – as seen with the average accelerations and decelerations for each starting speed bandwidth interval (Table 13), and when comparing the maximal efforts between subsequent starting speed intervals (Figure 17). As so, we recommend that assessing maximal accelerations for each starting speed interval, while assessing maximal decelerations as the maximal overall value, independent of the starting speed. This partially aligns with our hypothesis. That is, players achieve lower acceleration magnitudes at higher starting speeds, but higher decelerations magnitudes are achieved in different starting speeds. This is probably because players perform sudden stops from lower speeds, while slowly decelerate when at higher starting speeds, protecting themselves.

We assessed maximal accelerations and decelerations efforts during training sessions, instead of performing field tests. Although it can be questioned if the maximal efforts represent players' maximal capacities, we considered four microcycles to collect maximal efforts. As so, using only one match or one training session could mislead practitioners regarding maximal values. However, field tests can also mislead practitioners with players failing to replicate their field tests maximal speeds during matches (205,206). Other limitation relates to our sample consisting only of training sessions. Specifically, it would be interesting to assess if players "protect" themselves when decelerating during matches. However, we stress that this study aimed to adapt the original method proposed by Sonderegger et al. (12), so it can be considered a methodological study.

As so acceleration and deceleration monitoring should be individualized and not arbitrary, with intensity efforts representing a percentage of the maximal individual effort. Additionally, when assessing accelerations intensity, practitioners should assess the maximal acceleration for each starting speed bandwidth interval – as acceleration capacity diminishes as the starting speed increases; but when assessing decelerations intensity, practitioners should assess the maximal deceleration regardless of the starting speed – as deceleration capacity is less dependent on the effort starting speed. Finally, very-low intensity efforts (<25%) should be excluded from overall acceleration and deceleration demands, because these efforts potentially represent insignificant velocity changes, occurring mostly (~80%) from < 5 $km{\cdot}h^{-1}$ starting speeds.

Conclusions

We presented an adaptation of the percentage intensity approach, by assessing maximal accelerations and decelerations from training data. To assess maximal values, we recommend consider the maximal acceleration for each starting speed interval, and the overall maximal deceleration, independent of starting speed intervals. This is justified by the higher dependence of acceleration than deceleration to the starting speed during training sessions. Finally, considering low, moderate and high intensities would provide the fundamental information to practitioners, without excluding relevant efforts. This strategy can be used to replace the absolute thresholds method, with two major advantages: individualization of players' capacities/demands and ability to assess players according to their physical performance during real-life scenario such as training sessions.

Practical Applications

To move beyond the absolute and arbitrary thresholds, a relative intensity proposal was presented in this study. With this, practitioners can assess the training load with an individualize strategy, which considers players capacities. It is important to notice that we used the real scenario to establish the peak values instead of testing players. Although field tests could provide a true maximal capacity for each effort, training load would still be assessed and evaluated with a specific scenario that can or not be replicated during training sessions or even matches. Increasingly, using an individual sessions or match to categorize peak values should be avoided, since variability between activities/days can be expected.

4.5. Study V (Goalkeeper horizontal accelerations and decelerations during soccer training: varying exercises could be the best option)

Citation: Silva H, Nakamura FY, Bajanca C, Otte F, Pinho G, Moreno-Pérez V, Marcelino R. Goalkeeper horizontal accelerations and decelerations during soccer training: varying exercises could be the best option. (This study is currently under review by a scientific journal)

Abstract

Goalkeeping in soccer is a position with unique physical demands that receives less research attention than other playing' positions. To provide insight into goalkeeper-specific physical training loading, this study aims to compare acceleration and deceleration demands during different exercise categories: complementary (i.e., individualized training for the goalkeeper(s) not integrated during team drills), integrated (i.e., team-based exercises not specific for the position) and specific training (i.e., exercises that focus on the development of position-specific tactical-technical and physical capabilities). Three goalkeepers from one team competing in the U23 Portuguese league were monitored during four microcycles training sessions. Acceleration and deceleration demands were retrieved through GPS 10 Hz technology, including the effort starting speed. Efforts intensities were classified relatively and individually (low: 25-50%; moderate: 50-75%; high: > 75%). Mean ± SD were calculated to the number of efforts per minute for all exercises, and paired mean differences were used to assess differences with effect sizes between exercises. Results show that very few efforts started with higher speeds, and less than one high-intensity effort per minute occurred overall. 'Specific' and 'integrated' exercises elicited more high-intensity efforts than 'complementary' exercises (acceleration, ES: 0.61 [0.22, 1.65], ES: 0.61 [0.36, 1.47]; and deceleration, ES: 0.76 [0.50, 2.13], ES: 0.42 [0.42 [0.26, 1.01] respectively). Goalkeeping is a singular position in soccer and different exercise categories are needed to provide different resources to players: from simulating match demands, such as the 'integrated' exercises with outfield players, to improving goalkeepers' capabilities with 'specific' and 'complementary' exercises.

Keywords: football, global positioning system, planning, sprint, training load

Introduction

The goalkeeper (GK) in soccer is a unique playing position with very specialized and complex demands (207,208). Because the GK is the only player allowed to play the ball with hands, inside the own area, the GK's abilities to stop opponent goal opportunities can have huge impact on the match score and further provide distinctive possibilities for teams in possession of the ball (209). Specifically, in terms of actions, GKs frequently are exposed to shots, high crosses, and one-on-one situations (210) that alternate with long periods of no direct involvement in the match (211). Additionally, previous research on competition has found that based on teams' and individual players' tactical and contextual preferences, GK often play a role in the offensive part of the match (211). Indeed, currently more offensive actions, such as passing the ball, have been registered in comparison with defensive actions (209,212). Subsequently, the quality of offensive actions (e.g., receive passes, ability to pass forward, and distribute the ball well) distinguished elite from sub-elite GKs, and may be justified by the different playing styles and the evolving playing philosophy (213,214). In this regard, a ball possession approach may require a more proficient participation of the GK in the offensive phase of the match and that capability can impact the success of the team (214).

The match performance of the GK has been highlighted in the literature, reporting a technical evolution leading to fewer actions overall, with higher quality executions (212), and with the prevalence of offensive actions in matches (209,212). To transfer this knowledge to GK-specific training, a previous study by Jara and colleagues (215) reported more defensive and offensive actions in smaller formats of sided matches. However, since software to assess technical actions is usually not available in training sessions, research more often focuses on monitoring physiological GK demands in training and matchs. Inversely to what happens during technical actions, physical and physiological demands of the GK appear to be consistent over time (214), with this position covering shorter distances than any other playing position (209,210) and usually underreach as many high-intensity efforts as outfielders (208). However, the intense efforts that occur for the GK during matches appear to be abrupt and may often end up being critical actions, especially sprints between 0 and 5 meters (216). Considering these short distances and the abrupt characteristic of the intense efforts (217), analysis of acceleration (ACC) and deceleration (DEC) have become particularly important to GK performance (210).

For various reasons, ACC and DEC performances and GK' efforts may vary between training and matches, and equivalent or higher efforts than matches may be reported during the middle of the week training sessions (30). For example, higher ACC and DEC demands were reported in small sided-games than in larger formats, exposing differences between exercises variables (36). Generally, GK-specific training aims to replicate match demands and is composed of technical and complex/game-representative parts that should include a holistic training approach (i.e., coupling perception of match-relevant information, decision-making tasks and the physical coordination of GK actions) (177). To the best of our knowledge, no study to date has investigated the different physical GK training exercises demands. This examination has already been done on outfield positions, showing higher demands in sided games than circuit training (27,31) or continuous and shuttle running drills (22,150). These results could be of paramount importance for strength and conditioning coaches as well as GK coaches, in order to evaluate and optimize training programs. Therefore, the purpose of this study is to compare ACC and DEC demands of different exercise categories of GK training in one soccer mesocycle and apply this knowledge to training session design.

Methods

Subjects

Three GK with an average age of 18.3 ± 1.5 years, an average height of 187.0 ± 4.4 cm and an average weight of 78.0 ± 8.0 kg participated in this study. GPS unit data from 19 training sessions were collected. Ethics Committee clearance was obtained by the University Institute of Maia (35/2021) and the study was conducted in accordance with the Declaration of Helsinki. Written consent was obtained by the club.

Study design

A cross-sectional comparative study was conducted to compare different exercises categories during goalkeepers' training. Data were recorded using GPS units (units (Catapult G7; Catapult Sports, Melbourne, Australia) with built-in accelerometers during training sessions of an U23 team competing in Revelation League (Portuguese U23 League) during the 2020/21 season. The team completed a total of 19 sessions and four matches during the analyzed mesocycle. Notably, during the matches 2 GKs played for the team, with one of these usually training with the first team squad. As so, match data was excluded from this analysis. The entire training mesocycle was completed on a natural grass surface.

Procedures

Training exercises were divided in different categories, previously established by the coaching staff, and without any interference or adaptation for research purposes: 1) *Complementary* (i.e., exercises that address specific goalkeeper needs, in a more individualized approach, specific to the GK(s) that were not integrated during a team drill); 2) *Integrated* (i.e., exercises with no GK-specific content, where outfield players participated with higher technical/tactical objectives, such as offensive organization exercises, small-sided games with GK, or shooting drills.; and finally, 3) *Specific* (i.e., exercises that focused on the development of technical, tactical, and physical capabilities specifically related to the position, such as shooting and crossing drills, distribution drills, positioning, and feet orientation depending on ball position drills).

GPS devices were used (Catapult G7; Catapult Sports, Melbourne, Australia) with sampling frequencies of 10 Hz, which have shown a good level of accuracy to assess running patterns in soccer (45). The GPS unit was placed on the upper middle back between the scapulae of the subject using special protective vests as recommended by the manufacturer. This equipment is a certified FIFA Electronic Performance and Tracking System (190). The variables used to record the external demands were the number of accelerations (ACC) and decelerations (DEC) and the time in each exercise for the relative count (number of efforts per minute). Each effort was counted from the start of the velocity increase or decrease until the change in velocity reached 0 $m{\cdot}s^{-2}$ (218). ACC and DEC intensities were classified with the percentage intensity (low-intensity: 25-50%; moderate-intensity: 50-75%; high-intensity: > 75%) in reference to the maximal effort achieved by each player and according to the respective starting speed interval (219), a method that adapted the Sonderegger and colleagues' proposal (24). To retrieve the maximal effort, we collected the higher ACC and DEC value of the mesocycle of each player, excluding isolated values. For example, if the maximal ACC value was 7.30 $m{\cdot}s^{-2}$, another value between 7-8 $m{\cdot}s^{-2}$ had to exist for this value to be considered maximal. Additionally, the starting speed of each ACC and DEC was also collected according to bandwidth intervals: (< 5 $km{\cdot}h^{-1}$, 5-10 $km{\cdot}h^{-1}$, 10-15 $km{\cdot}h^{-1}$, 15-20 $km{\cdot}h^{-1}$, 20-25 $km{\cdot}h^{-1}$ and > 25 $km{\cdot}h^{-1}$) (219).

Statistical analysis

Mean ± SD was calculated for each effort during each exercise and for each ACC and DEC intensity interval and starting speed interval. Paired mean differences were estimated in jamovi using the ESCI package (192,193). Two different measures were analyzed separately: the number of efforts of one player during one exercise was compared to the number of efforts of that same player for other exercise. This procedure was conducted for each exercise and for each ACC and DEC intensity interval and for each starting speed interval. Effect sizes (ES) calculated as Cohen's d were interpreted as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). If the CI crossed both positive and negative values, an unclear effect size was established (55).

Results

More relative efforts were performed in lower intensities and lower starting speeds (Figure 18; and Table S2 in Supplementary Information). Less than 1 effort (ACC/DEC) per minute was registered in intensities > 50% and in DEC with intensities > 25%. Similarly, less than 1 effort per minute was registered in starting speeds > 10 $km{\cdot}h^{-1}$ (Figure 19; and Table S3 in Supplementary Information).

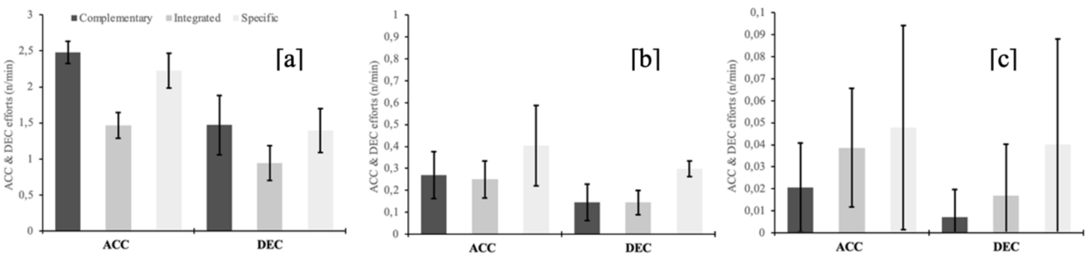

Figure 18. Number of accelerations and decelerations per minute (Mean ± SD) for each exercise category and for each intensity interval (25-50% [a], 50-75% [b] and > 75% [c]) for all players (n=3). ACC=acceleration; DEC=deceleration.

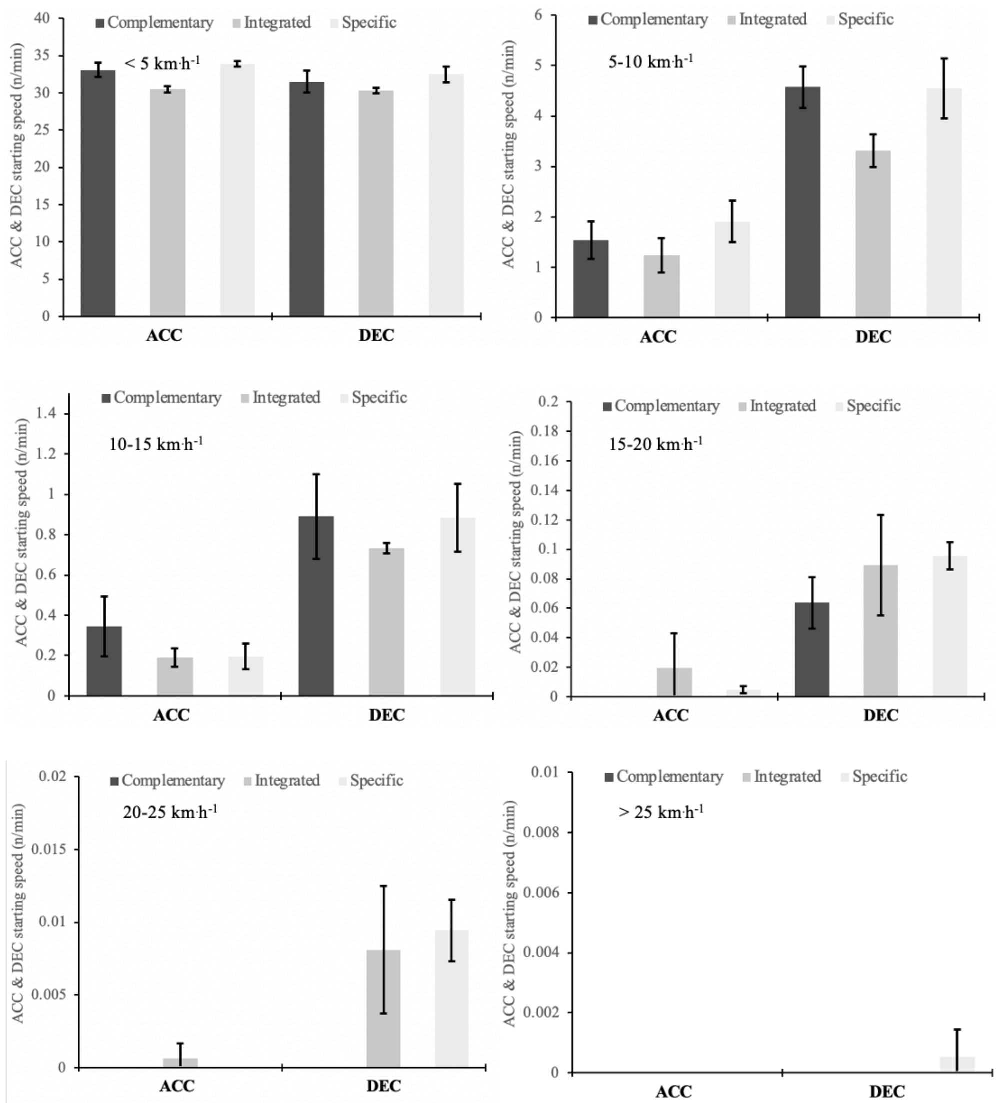

Figure 19. Number of accelerations and decelerations per minute (Mean ± SD) according to the starting speed (< 5 $km{\cdot}h^{-1}$, 5-10 $km{\cdot}h^{-1}$, 10-15 $km{\cdot}h^{-1}$, 15-20 $km{\cdot}h^{-1}$, 20-25 $km{\cdot}h^{-1}$ and > 25 $km{\cdot}h^{-1}$) of each effort that occurred in each training exercise category for all players (n=3). ACC=acceleration; DEC=deceleration.

Except for ACC and DEC > 75% (moderate ES: 0.61 [0.36, 1.47]; small ES: 0.42 [0.26, 1.01]) and DEC starting > 15 km·h^{-1} (moderate ES: 0.76 [0.30, 2.02]), complementary exercise had higher demands than the integrated exercises. ES ranged from huge (ACC 25-50%, ES: 4.85 [2.71, 12.03]), very large (ACC 0-5 km·h^{-1}, ES: 2.79 [0.91, 7.65]; DEC 5-10 km·h^{-1}, ES: 2.71 [1.76, 6.45]), large (DEC 25-50%, ES: 1.25 [0.82, 3.52]; ACC 10-15 km·h^{-1}, ES: 1.14 [0.73, 2.71]), moderate (DEC 10-15 km·h^{-1}, ES: 0.85 [0.31, 0.2.29]) and trivial (ACC 50-75%, ES: 0.16 [0.10, 0.39]) (Figure 20).

Specific exercises elicited had higher demands than complementary exercises except for ACC and DEC starting at 10-15 km·h^{-1} (moderate ES: 1.05 [0.62, 2.58] and trivial ES: 0.03 [0.02, 0.09] respectively). ES ranged from large (DEC 50-75%, ES: 1.93 [1.05, 4.83]; DEC 15-20 km·h^{-1}, ES: 1.85 [0.05, 5.65]), moderate (DEC > 75%, ES: 0.76 [0.50, 2.13]; ACC 50-75%, ES: 0.72 [0.42, 1.75]; ACC > 75%, ES: 0.61 [0.22, 1.65]; ACC 5-10 km·h^{-1}, ES: 0.76 [0.46, 1.85]) (Figure 20).

Specific exercises had also elicited higher demands than integrated exercise. ES ranged from huge (ACC 0-5 km·h^{-1}, ES: 6.72 [4.11, 16.27]), very large (ACC 25-50%, ES: 2.83 [1.67, 6.94]; DEC 50-75%, ES: 2.61 [1.71, 7.32]; DEC 0-5 km·h^{-1}, ES: 2.18 [1.19, 5.45]; DEC 5-10 km·h^{-1}, ES: 2.06 [0.9, 5.4]), large (ACC 5-10 km·h^{-1}, ES: 1.40 [0.69, 3.6]; DEC 25-50%, ES: 1.32 [0.77, 3.23]), moderate (ACC 50-75%, ES: 0.86 [0.54, 2.08]; DEC 10-15 km·h^{-1}, ES: 1.00 [0.42, 2.63]), and small (DEC > 75%, ES: 0.49 [0.31, 1.19]) (Figure 20).

The remaining differences were considered unclear because ES 90% CI crossed both sides. Full data available at Table S4 in Supplementary Information.

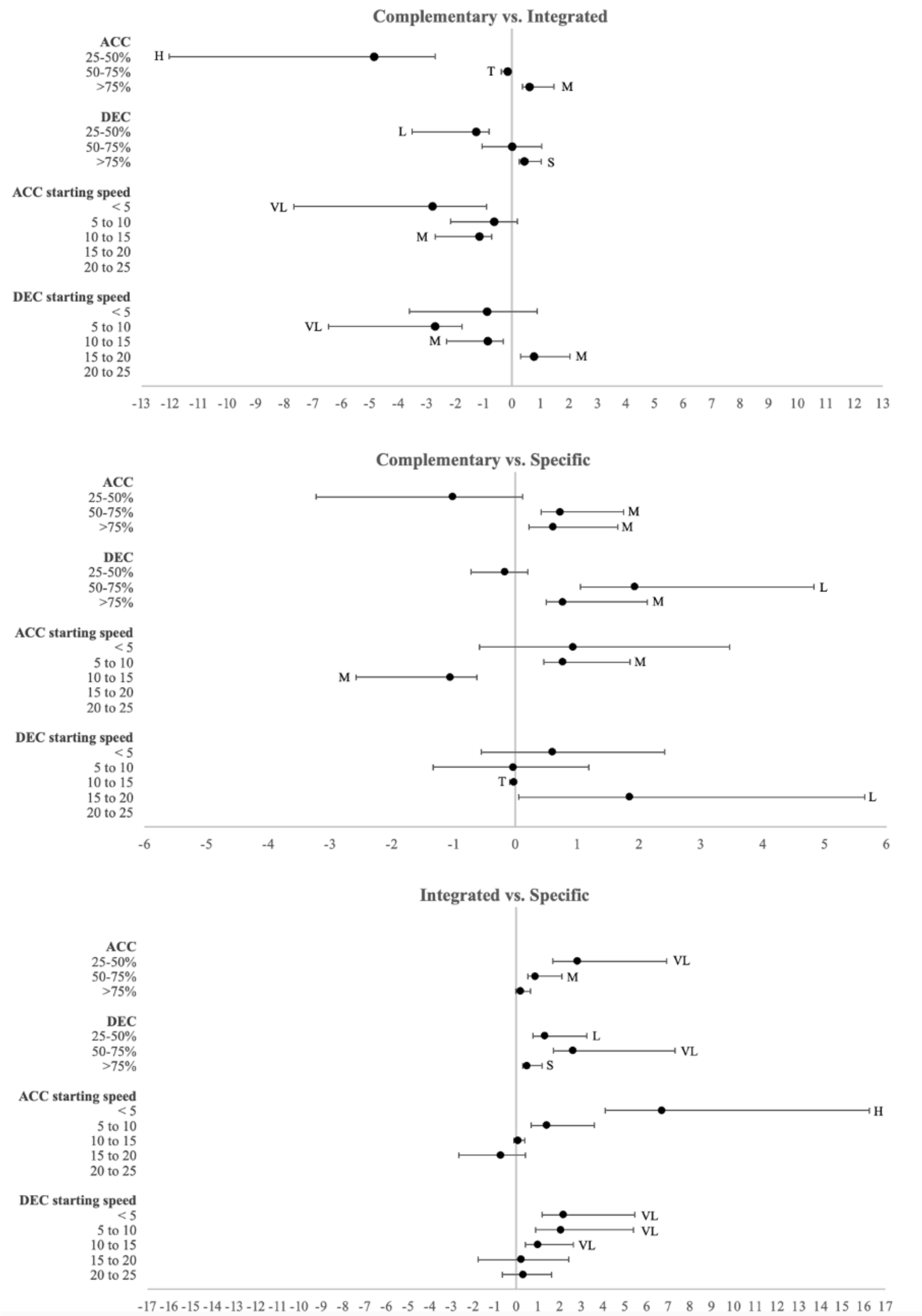

Figure 20. Standardized mean differences (Effect Size with 90% Confidence Interval) between different exercise categories for accelerations and decelerations per minute according to the respective intensity percentage interval, and to the respective starting speed ($km \cdot h^{-1}$) interval. ACC=acceleration; DEC=deceleration. H=huge effect size (>4.0); VL=very large effect size (2.0<4.0); L=large effect size (1.2<2.0); M=moderate effect size (0.6<1.2); S=small effect size (0.2<0.6); T=trivial effect size (<0.2).

Discussion

The aim of the present study was to compare acceleration (ACC) and deceleration (DEC) demands of different exercises in soccer GK training during a mesocycle. Our main finding highlights that lower intensities for ACC and DEC and the respective effort's starting speed, occur more frequently than higher intensities, regardless of the exercise' category. Concerning the novel comparison between exercise categories for soccer GKs (i.e., here divided into specific, integrated, and complementary exercises), specific exercises elicited higher demands than complementary and integrated exercises, respectively. In the following, results are discussed from an integrated perspective, applying empirical findings to practical soccer (goalkeeping) coaching.

Generally, GK training sessions mostly differ from sessions of their outfield playing teammates. While it is well known that the soccer GK position encompasses unique match demands (208), specific training exercises that promote the ability to catch, deflect and punch the ball under different contexts and constraints are important and occasionally appear to elicit higher physical demands than during competitive matches (220). In addition, GKs need specific stimuli in training to develop physical (as well as tactical-technical) capabilities to perform particular actions such as dives, jumps or quick reactions (220). Interestingly, GK can go by without significant physical and mental effort, but higher technical participation if their team is able to dominate the opposition during matches (214,217). All these factors should be accounted for when developing exercises and managing physical intensities for goalkeeping training. In the present study we identified that less than 1 high-intensity (> 75%) ACC or DEC occurred per minute in each of the three different training exercise categories (i.e., complementary, integrated, and specific). This is in line with previous research that stated that intensive efforts occurred mainly between 0 and 5 meters (216) and only represented 1% of the total distance covered (211). The relative number of ACC and DEC efforts vary by exercise category and for effort intensity. When comparing high-intensity efforts (> 75%), we found unclear (ACC) and small (DEC) effect sizes between integrated and specific exercises, and a moderate (ACC) and small (DEC) effect sizes favoring integrated exercises in comparison with complementary exercises.

Comparisons with previous studies are difficult, as research comparing exercise categories is scarce. However, one previous study reported higher intensity actions (including explosive efforts) in GK activities, that could be interpreted as 'specific exercises' compared to small-sided games (i.e., a form of 'integrated exercises', according to our differentiation) (220). Our study addresses this need, providing important information which can help coaches plan for GK training sessions.

The starting speed provides an interesting insight for GK training analysis. For instance, during integrated exercises, GKs are expected to be in their position and quickly react to a specific situation, such as rushing from the goal to intercept a ball. This is in line with our findings, where GKs performed less efforts during integrated training exercises starting from lower speeds (< 10 $km \cdot h^{-1}$). Those differences started to dissipate as the starting speed increased, especially when less than 0.1 ACC/DEC per minute occurred. Since GKs spend almost the entire match (96%) standing or walking/jogging (221), integrated exercises display similar match context for the position. This is important because (match-)representative learning design and increased problem-solving activities for players within match-realistic environments are proven to be beneficial for player development (222).

Specific training, however, may methodically intend to develop GK capabilities, so high loads would be expected. This approach is in line with periodization, where players need to develop their readiness to perform (223), while matches could fail to provide a sufficient physical stimulus to GKs (220).

Despite some previous efforts to investigate the GK position, to date, this playing position is scarcely examined in comparison with outfield players in soccer. However, based on previous research into positional differences (224), it appears only logic that the GK position requires different (match-realistic) training approaches and physical stimuli/ loadings compared to outfield positions (208). Here at times, training exercises may differ from match demands (e.g., considering the overload principle (225)).

Overall, more research into the GK position and the transfer of empirical knowledge to training planning is needed and this study aimed to help bridge this gap. For example, one could adapt the type of exercise and physical efforts with how the team is expected to perform in a match. If one team is expected to dominate the opponent, this team's GK would be exposed to fewer high-intensity ACC and DEC demands by being rarely exposed to defensive actions but could perform more efforts starting from higher starting speeds (i.e., the ball is expected to be away from GK which could provide more space to run). In contrast, if the team is expected to be dominated by opposition, the ball would be closer to the GK, whom could be exposed to more intense and short actions.

Finally, several limitations exist as to the interpretation of data in this study. Our findings relate to a specific sample (i.e., three male GKs playing in Portugal's U23 league) and to a particular coaching staff that designs exercises in their specific way. Hence, generalizing exercise categorization represents a difficulty in this type of research as different staff in different countries/leagues/organizations use different strategies and training methodologies. Consequently, future studies with higher sample sizes are necessary. Furthermore, this study is limited to the measurement of horizontal displacements (i.e., ACC and DEC), while further specific GK actions, such as dives and jumps, were not considered and certainly place physical demands on GK. However, goalkeeping in soccer is not separated from the sport's particularities, such as performance, fatigue and injuries. As so, practitioners should thoroughly periodize training interventions and carefully monitor their players to ensure that the desired development is being achieved and that fatigue and injury risk is as low as possible.

Conclusions

This study demonstrated that different GK exercises elicit different demands. Specifically, specific exercises, that aim the development of GK capabilities, elicit higher demands than integrated and complementary exercises. Interestingly, integrated exercises elicited more efforts with higher intensity and higher starting speeds than complementary exercises. With the aim of further supporting this planning process, the present study showed that specific training exercises elicited more high-intensity efforts than integrated and compensatory exercise categories. However, each exercise category provided a different stimulus to GK, with the integrated category providing players with a more similar match context. As so, variability between exercises can provide different, but critical, stimuli.

Practical Applications

Considering the uniqueness of the GK position, varying training exercises may be the best option to provide different acceleration and deceleration stimuli. In soccer, coaches should evaluate goals and objectives prior to planning training sessions for all positions, including the GK. Since competition can impose different demands according to the own team's playing style and opposition characteristics, coaches should periodize training and prepare their players for what they intend.

4.6. Study VI (Acceleration and deceleration demands during different soccer activities)

Citation: Silva H, Nakamura FY, Bajanca C, Pinho, G, Serpiello FR, Marcelino R. Acceleration and deceleration demands during different football activities. (This study is currently under review by a scientific journal)

Abstract

The purpose of this study was to compare the acceleration and deceleration demands between different soccer training drills and competitive matches, and between playing positions. Nineteen professional players were monitored during four microcycles (training sessions and matches). Accelerations and decelerations demands were categorized according to drills: compensation, rondos, small-sided games, technical and matches. Efforts intensities were classified as low (25-50%), moderate (50-75%) and high (>75%); starting speed was assessed in bandwidth (< 5 $km{\cdot}h^{-1}$, 5-10 $km{\cdot}h^{-1}$, 10-15 $km{\cdot}h^{-1}$, 15-20 $km{\cdot}h^{-1}$, 20-25 $km{\cdot}h^{-1}$, and > 25 $km{\cdot}h^{-1}$). Comparisons between drills and matches were estimated with paired mean differences, and comparisons between playing positions were estimated with independent groups contrasts, with 90% confidence intervals. Match elicited more high-intensity accelerations than technical drills (ES: 1.75 [1.40, 2.28]), rondos (ES: 1.47 [0.92, 2.17]), compensation drills (ES: 1.28 [0.66, 2.09]), and small-sided games (ES: 0.64 [0.11, 1.25]), and more high-intensity decelerations than technical drills (ES: 0.74 [0.24, 1.32]) and rondos (ES: 0.53 [0.04, 1.06]). Compensation drills elicited more accelerations and decelerations starting > 20 $km{\cdot}h^{-1}$ than matches and other drills (small to very large effect sizes). Wide positions generally performed more high-intensity accelerations during small-sided games and technical drills, and central defenders performed less efforts at higher speeds (>20 $km{\cdot}h^{-1}$) during matches. Match imposed higher demands to players than any drill, and compensation and small-sided games elicited more efforts starting at higher speeds and with higher intensity respectively. Rondos drills should be carefully used due to the high deceleration demands imposed to players.

Keywords: drill, game, planning, soccer, training load

Introduction

Soccer training has two main objectives: to increase collective and individual performance and to decrease the injury risk (226). By decreasing players' injury risk, teams can increase the possibility of competing to their maximal capacities. Muscle injuries represent almost one third of all soccer injuries, with non-contact hamstring injuries dominating the occurrences (227), especially in situations involving high-intensity movements (e.g., sprints) (188). Another important injury, especially due to the prolonged recovery time, is to anterior cruciate ligament, that usually occurs in a deceleration (DEC) task combined with dynamic valgus rotation (228). This highlights the importance of monitoring explosive efforts, helping coaches and practitioners to constantly adjust loads to prevent excessive fatigue and musculoskeletal stress, thus reducing injury risk (112,226). Even though the relation of injuries and training is complex and multifactorial (229), monitoring of these actions can help reduce their harmful effects, especially concerning DEC demands (9).

Regarding performance, one can discuss the team and individual player performance. From a team perspective, accelerations (ACC) and DEC can have a positive impact on the match outcome (230–232), but it is important to highlight that match load can be affected by contextual variables such as the opposition level (233) and time played (234). In the individual perspective, it was found that players with higher capacity in these explosive movements were able to jump higher, sprint faster over short distances, and achieve higher change of direction speeds (235).

Training sessions should be carefully planned and monitored to ensure that the planned physiological adaptations are achieved (117,236). Therefore, choosing what drills to use assumes particular importance as they can provide different stimuli and drive specific adaptations. For instance, ACC frequency (per minute) was higher during small-sided games (SSG) (4 vs. 4) than matches, but similar to peak match periods (237). SSG also elicited higher ACC and DEC demands than circuit training (27) and continuous and shuttle running (22). However, research comparing different drills is scarce, and authors have previously investigated differences between sessions according to its objectives. For instance, Campos-Vázquez et al. (78) reported higher demands in friendly matches in comparison with activation (warm-up, finishing actions at maximum speed, 11vs.11 for 15-20 minutes and set pieces), fitness (strength training, high-intensity interval training and conditioning/SSG), reserves fitness (compensation session to non-starters) and tactical (conditioned 11vs.11 in moderately large spaces) sessions. In contrast, other study (28) reported higher ACC and DEC demands in training sessions with SSG (4vs.4), mini goals (4vs.4), and large sided games (8vs.8), in comparison with friendly games (11vs.11) and sessions with circuit drills (1vs.1). Since coaches frequently apply SSG during training, these drill formats have been intensely investigated, with higher ACC and DEC demands in smaller formats (number of players or area of play) (194). However, in practice, coaches vary drills to avoid training monotony and motivate their players. For this reason, it is important to thoroughly analyze ACC and DEC demands in drills commonly used by coaches, providing information of what load those drills would impose on their players.

Therefore, the aim of this study was to: i) compare the ACC and DEC demands between different football drills and competitive matches; ii) compare the different drills between them; and iii) compare demands between playing positions.

Methods

Study design

Data were collected using GNSS units during training sessions and matches from one team belonging to the Revelation League (Portuguese U23 League) during four weeks of the 2020/21 season. Data were retrieved during the in-season period, with one match per week. Raw data from 19 training sessions and 4 matches were collected from each player and we calculated the physical demands in terms of the number of ACC and DEC and the time in each drill using relative counts (number of efforts per minute). The starting speed of each effort (ACC and DEC) was also analyzed.

Subjects

The initial participants sample comprised 33 team members; however, we excluded those players who did not participate in a minimum of 50% of training sessions and matches, as well as goalkeepers, were excluded. A total of 19 players with mean ±

SD age, height and weight of 20.1 ± 1.2 years, 179.9 ± 4.5 meters, and 75.8 ± 6.0 kilograms, respectively, were selected to proceed with analysis. Players were divided according to their playing' positions: 3 central defenders (CD), 4 fullbacks (FB), 6 central midfielders (CM), 4 wide midfielders (WM) and 2 forwards (FW). Players wore GNSS tracking devices as required for training routine monitoring and accepted data sharing for research purposes. For this reason, Ethics Committee clearance was not required (48). Written consent was obtained by the club.

Training drills & Matches

Drills were previously established by the coaching staff, without any interference or adaptation for research purposes. Drills performed only once or did not relate to one of the comparison categories, were excluded. This category division followed the team coach classifications and instructions: Compensation: drills with a strong physical component, composed by high-speed running drills performed during the training sessions in the day after the matches (MD+1). Rondos: consisted in a simple passing game, usually with ball touches limitations, and with one or two players trying to recover the ball. SSG: Drills with game similarities, in the 4vs4 format. Technical: drills that aimed the development of technical actions such as passing, dribbling, or shooting. Matches: competition for all participating players (substitutes playing time was considered). To prevent skewing data collection, we discounted 1 minute for players that exit or enter the game. For example, if one player had been substituted at the 75th minute, we only recorded his data until the 74th minute, excluding data that did not relate to the match. Equally, for the player that entered at the 75th minute we only retained the data after the 76th minute.

GNSS analysis

We used GNSS units (Catapult S7; Catapult Sports, Melbourne, Australia) with sampling frequency of 10 Hz and certified by FIFA (190). The units were placed on the upper middle back between the scapulae of the subject using special protective vests recommended by the manufacturer.

Each ACC and DEC was counted from the start of the velocity increase or decrease until the change in velocity reached 0 $m \cdot s^{-2}$ (218). ACC and DEC intensities were established with the percentage intensity approach (219), which adapted the Sonderegger proposal (24), at 25-50% (low intensity), 50-75% (moderate intensity) and > 75% (high intensity). To retrieve the maximal effort, we collected the highest ACC and DEC value of the mesocycle of each player, excluding isolated values. For example, if the maximal ACC value was 7.30 $m \cdot s^{-2}$, another value between 7-8 $m \cdot s^{-2}$ had to exist for this value to be considering as maximal.

The starting speed of each ACC and DEC was also collected according to bandwidth intervals: (< 5 $km \cdot h^{-1}$, 5-10 $km \cdot h^{-1}$, 10-15 $km \cdot h^{-1}$, 15-20 $km \cdot h^{-1}$, 20-25 $km \cdot h^{-1}$, and >25 $km \cdot h^{-1}$) (219).

Statistical analysis

Mean ± SD was calculated for each effort during each drill and for each ACC and DEC intensity interval and starting speed interval.

Paired mean differences were estimated in jamovi using the ESCI package (192,193). Two different measures were analyzed separately: the number of efforts of one player during one drill was compared to the number of efforts of that same player for other drill. This procedure was conducted for each drill and for each ACC and DEC intensity interval and for each starting speed interval. Cohen's (*d*) effect sizes were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). If the CI crossed zero, an unclear effect size was established (55). Playing positions were compared using number of ACC and DEC per minute, according to drill. Differences were estimated with independent groups contrasts, with 90% CI, in jamovi with ESCI package (192,193). If the 90% CI crossed zero, differences were considered unclear.

Results

Table 14. Mean ± SD of efforts per minute for each training drill and competition matches according to efforts intensity (25-50%, 50-75%, >75%) and efforts starting speed (< 5 km·h⁻¹, 5-10 km·h⁻¹, 10-15 km·h⁻¹, 15-20 km·h⁻¹, 20-25 km·h⁻¹, and >25 km·h⁻¹).

	Compensation	**Rondos**	**SSG**	**Technical**	**Matches**
ACC					
25-50%	0.72±0.39	4.58±0.91	3.88±1.32	3.03±0.51	2.96±0.95
50-75%	0.09±0.14	0.67±0.31	0.78±0.40	0.45±0.16	0.64±0.22
>75%	0.03±0.08	0.05±0.06	0.09±0.09	0.04±0.03	0.13±0.07
DEC					
25-50%	0.24±0.20	2.73±1.45	2.56±1.47	1.44±0.69	1.48±0.68
50-75%	0.02±0.07	0.29±0.21	0.31±0.31	0.15±0.10	0.24±0.17
>75%	0.00±0.00	0.0±0.0	0.02±0.04	0.02±0.02	0.04±0.04
ACC starting speed					
<5 km·h⁻¹	27.49±7.62	33.91±5.83	29.24±3.65	27.52±2.63	22.02±6.61
5-10 km·h⁻¹	12.16±8.38	1.30±0.64	3.43±1.18	4.01±1.26	8.25±2.62
10-15 km·h⁻¹	0.41±0.47	0.06±0.16	0.44±0.30	0.87±0.29	3.25±1.24
15-20 km·h⁻¹	0.33±0.71	0.01±0.04	0.06±0.07	0.07±0.05	0.70±0.41
20-25 km·h⁻¹	0.39±0.44	-	0.00±0.00	0.01±0.02	0.15±0.10
>25 km·h⁻¹	0.14±0.13	-	-	-	0.03±0.02
DEC starting speed					
<5 km·h⁻¹	25.96±7.81	29.78±6.10	23.29±5.60	24.47±2.98	17.62±4.94
5-10 km·h⁻¹	13.79±8.83	5.25±1.93	8.03±2.08	6.42±1.64	9.80±3.04
10-15 km·h⁻¹	0.66±0.56	0.79±0.43	2.16±1.03	2.65±0.69	5.24±1.53
15-20 km·h⁻¹	0.34±0.74	0.03±0.07	0.53±0.40	0.56±0.15	1.81±0.70
20-25 km·h⁻¹	0.62±0.67	-	0.07±0.08	0.12±0.07	0.53±0.21
>25 km·h⁻¹	0.48±0.23	-	0.00±0.01	0.01±0.01	0.16±0.08

ACC=acceleration; DEC=deceleration; SSG=small-sided games.

Means ± SD of efforts per minute for each drill and matches are presented in Table 14. More low intensity ACC (88%) and DEC (79%) and more ACC (91%) and DEC (66%) starting at lowest starting speeds (< 5 km·h⁻¹) were performed by players regardless of drill. ACC starting > 25 km·h⁻¹ were only registered in compensation drills and matches. Differences between drills (mean paired differences) are presented in Table 15.

Table 15. Mean paired differences (effect sizes with 90% CI) between drills.

	Compensation vs. Rondos	Compensation vs. SSG	Compensation vs. Technical	Rondos vs. SSG	Rondos vs. Technical	SSG vs. Technical
ACC						
25-50%	5.48 (4.29, 7.33)^{H}	3.26 (2.45, 4.46)^{VL}	4.97 (3.88, 6.67)^{H}	-0.60 (-1.20, -0.06)^{M}	-2.05 (-2.72, -1.55)^{VL}	-0.83 (-1.45, -0.28)^{M}
50-75%	2.42 (1.73, 3.40)^{VL}	2.28 (1.63, 3.22)^{VL}	2.55 (1.92, 3.49)^{VL}	0.30 (-0.21, 0.85)	-0.88 (-1.33, -0.51)^{M}	-1.08 (-1.58, -0.68)^{M}
>75%	0.39 (-0.30, 1.14)	0.63 (-0.08, 1.42)	0.14 (-0.47, -0.76)	0.57 (0.14, 1.05)^{S}	-0.12 (-0.70, 0.46)	-0.73 (-1.31, -0.21)^{M}
DEC						
25-50%	2.00 (1.58, 2.67^{L}	1.99 (1.51, 2.71)^{L}	2.01 (1.59, 2.66)^{L}	-0.11 (-0.49, 0.26)	-1.11 (-1.44, -0.87)^{M}	-0.95 (-1.38, -0.61)^{M}
50-75%	1.77 (1.20, 2.56)^{L}	1.11 (0.70, 1.66)^{M}	1.47 (0.81, 2.31)^{L}	0.06 (-0.30, 0.44)	-0.81 (-1.19, -0.50)^{M}	-0.66 (-1.07, -0.31)^{M}
>75%	-	-	-	-0.01 (-0.65, 0.62)	-0.17 (-0.64, -0.29)^{T}	-0.12 (-0.65, 0.41)
ACC starting speed						
<5 $km{\cdot}h^{-1}$	0.88 (0.14, 1.73)^{M}	0.21 (-0.26, 0.71)	0.04 (-0.59, 0.69)	-0.94 (-1.53, -0.43)^{M}	-1.38 (-1.99, -0.90)^{L}	-0.53 (-1.10, -0.01)^{S}
5-10 $km{\cdot}h^{-1}$	-1.77 (-2.57, -1.19)^{L}	-1.40 (-2.13, -0.85)^{L}	-1.30 (-1.96, -0.81)^{L}	2.19 (1.61, 2.97)^{VL}	2.65 (2.15, 3.39)^{VL}	0.46 (-0.04, 1.00)
10-15 $km{\cdot}h^{-1}$	-0.91 (-1.53, -0.41)^{M}	0.20 (-0.38, 0.80)	1.14 (0.48, 1.95)^{M}	1.56 (0.98, 2.28)^{L}	3.33 (2.56, 4.39)^{VL}	1.41 (0.80, 2.15)^{L}
15-20 $km{\cdot}h^{-1}$	-0.61 (-1.35, 0.06)	-0.50 (-1.23, 0.17)	-0.49 (-0.85, -0.19)^{S}	0.92 (0.32, 1.59)^{M}	1.37 (0.83, 2.04)^{L}	0.17 (-0.40, 0.75)
20-25 $km{\cdot}h^{-1}$	-	-1.20 (-1.90, -0.65)^{L}	-1.17 (-1.97, -0.51)^{M}	-	-	0.71 (0.14, 1.34)^{M}
>25 $km{\cdot}h^{-1}$	-	-	-	-	-	-
DEC starting speed						
<5 $km{\cdot}h^{-1}$	0.50 (-0.24, 1.31)	-0.44 (-0.99, 0.06)	-0.24 (-0.91, 0.41)	-1.07 (-1.64, -0.60)^{M}	-1.08 (-1.63, -0.63)^{M}	0.24 (-0.32, 0.82)
5-10 $km{\cdot}h^{-1}$	-1.29 (-2.03, -0.72)^{L}	-0.89 (-1.51, -0.38)^{M}	-1.09 (-1.65, -0.67)^{M}	1.36 (0.75, 2.09)^{L}	0.58 (0.23, 0.98)^{S}	-0.82 (-1.49, -0.24)^{M}
10-15 $km{\cdot}h^{-1}$	0.43 (-0.27, 1.19)	2.05 (1.34, 3.02)^{VL}	2.93 (2.17, 4.06)^{VL}	1.79 (1.24, 2.50)^{L}	3.19 (2.55, 4.11)^{VL}	0.47 (-0.11, 1.10)
15-20 $km{\cdot}h^{-1}$	-0.56 (-1.32, 0.14)	0.37 (-0.34, 1.14)	0.37 (-0.19, 0.99)	1.77 (1.15, 2.53)^{L}	4.58 (3.72, 5.83)^{H}	0.05 (-0.48, 0.60)
20-25 $km{\cdot}h^{-1}$	-	-1.11 (-1.94, -0.42)^{M}	-1.00 (-1.80, -0.34)^{M}	-	-	0.60 (0.23, 1.03)^{M}
>25 $km{\cdot}h^{-1}$	-	-2.90 (-3.98, -2.18)^{L}	-2.88 (-4.02, -2.11)^{VL}	-	-	0.35 (-0.23, 0.96)

ACC=acceleration; DEC=deceleration; SSG=small-sided games. H=huge effect size (>4.0); VL=very large effect size (2.0<4.0); L=large effect size (1.2<2.0); M=moderate effect size (0.6<1.2); S=small effect size (0.2<0.6); T=trivial effect size (<0.2).

Figure 21 (data available at Table S5 in Supplementary Information) compares the number of ACC and DEC between the different drills and matches, according to the effort intensity. Figure 22 (data available at Table S5 in Supplementary Information) compares the number of ACC and DEC between the different drills and matches, according to the effort starting speed.

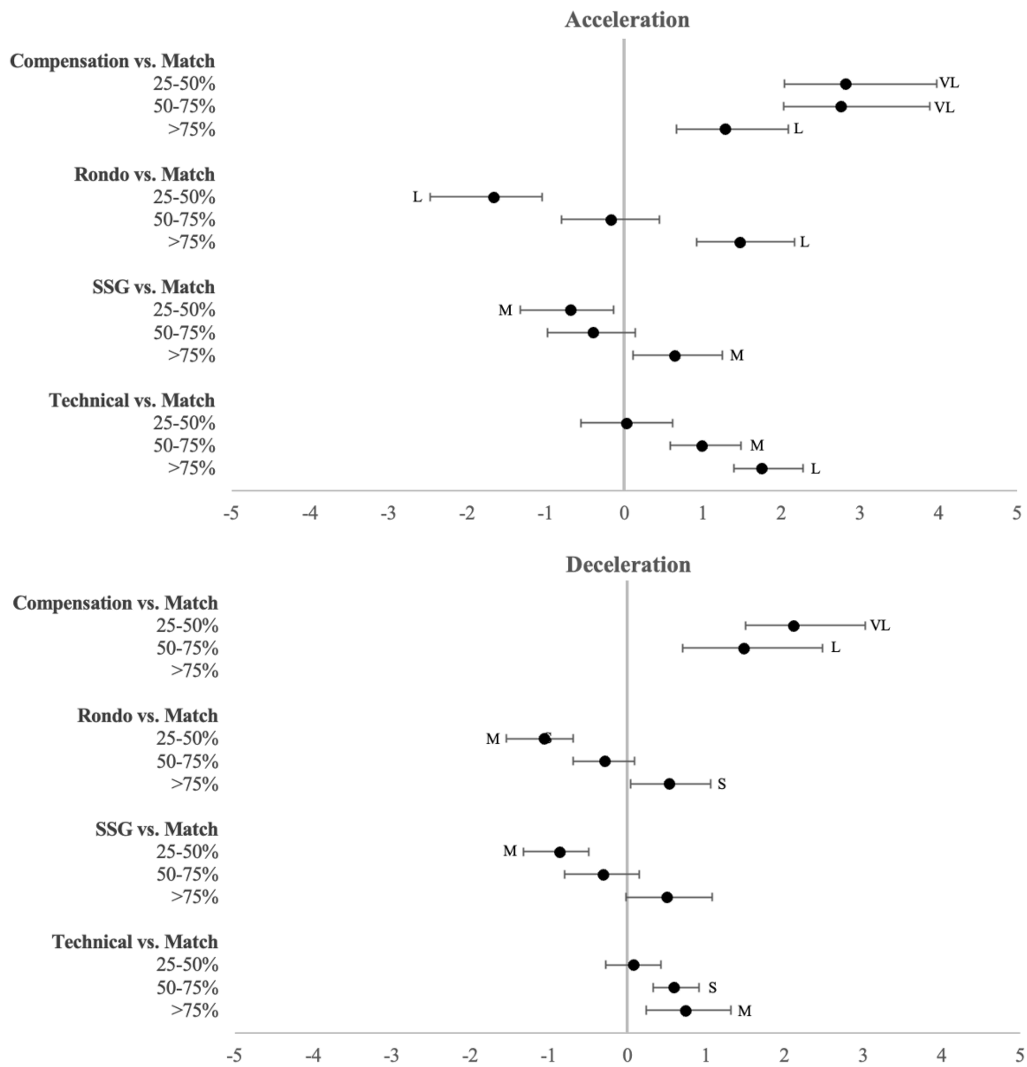

Figure 21. Standardized mean differences (effect Size with 90% Confidence Interval) between different drills and matches for accelerations and decelerations per minute according to the respective intensity percentage interval. SSG=small-sided games. VL=very large effect size (2.0<4.0); L=large effect size (1.2<2.0); M=moderate effect size (0.6<1.2); S=small effect size (0.2<0.6).

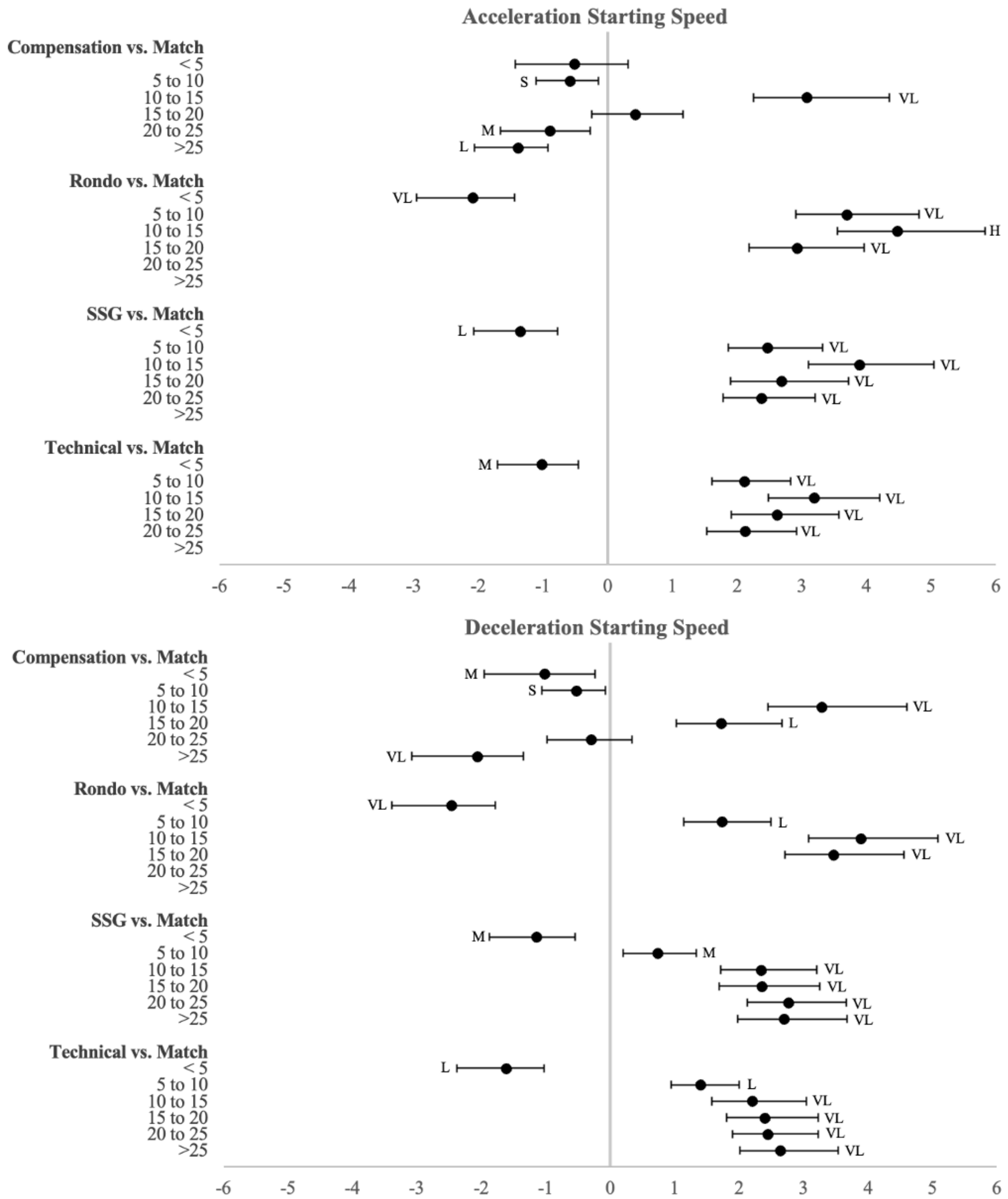

Figure 22. Standardized mean differences (effect Size with 90% Confidence Interval) between different drills and matches for accelerations and decelerations per minute according to the respective starting speed (km·h^{-1}) interval. SSG=small-sided games. H=huge effect size (>4.0); VL=very large effect size (2.0<4.0); L=large effect size (1.2<2.0); M=moderate effect size (0.6<1.2); S=small effect size (0.2<0.6).

Differences between playing positions

Compensation drills

No differences between positions were reported during compensation drills as only one FW performed them, impairing comparisons.

Rondo drills

This exercise elicited more low ACC for CM than FB (1.08 [0.09, 2.07]) and WM (1.02 [0.03, 2.01]), more moderate ACC for CM than FB (0.38 [0.04, 0.72]), more low DEC for CD, FB and CM than WM (2.45 [0.86, 4.04]; 1.97 [0.49, 3.44]; 2.46 [1.12, 3.80]), more moderate DEC for CD and CM than WM (0.32 [0.04, 0.59], 0.26 [0.02, 0.49]). Regarding efforts starting speeds, more DEC started < 5 $km{\cdot}h^{-1}$ for FW than CM (9.00 [0.20, 17.8]), more DEC started 5-10 $km{\cdot}h^{-1}$ for CM than FB (1.91 [0.25, 3.58]).

SSG

SSG elicited more high ACC for FB than CM (0.10 [0.01, 0.20]), more low DEC for CD and FB than WM (2.23 [0.37, 4.10]; 1.84 [0.11, 3.56]), more moderate DEC for CD than CM, WM and FW (0.43 [0.12, 0.75]; 0.64 [0.30, 0.98]; 0.57 [0.17, 0.98]) and for FB than WM (0.39 [0.07, 0.70]). Regarding efforts starting speeds, SSG elicited more ACC starting < 5 $km{\cdot}h^{-1}$ for CM than FB (5.16 [1.19, 9.14]), more ACC starting 5-10 $km{\cdot}h^{-1}$ for FB and WM than CM (1.77 [0.57, 2.96] and 1.52 [0.32, 2.71]), more ACC starting 10-15 $km{\cdot}h^{-1}$ for FB, WM and FW than CD (0.54 [0.20, 0.89], 0.48 [0.14, 0.83], 0.55 [0.14, 0.96]), more DEC starting < 5 $km{\cdot}h^{-1}$ for CM than FB (7.52 [1.29, 13,76]), more DEC starting 5-10 $km{\cdot}h^{-1}$ for CD than CM (2,71 [0.25, 5.17]), more DEC starting 15-20 $km{\cdot}h^{-1}$ for FB than CD and CM (0.53 [0.03, 1.04], 0.48 [0.06, 0.91]), more DEC starting 20-25 $km{\cdot}h^{-1}$ for FB than CD, CM and FW (0.12 [0.03, 0.20], 0.09 [0.02, 0.16], 0.13 [0.03, 0.23]), and for WM than CD, CM and FW (0.12 [0.04, 0.21], 0.10 [0.03, 0.17], 0.14 [0.04, 0.23]).

Technical drills

This drill category elicited more low ACC for CM than WM (0.60 [0.02, 1.18]), more moderate ACC for CD than CM (0.22 [0.01, 0.42]), more high ACC for WM than CD (0.05 [0.02, 0.08]), more low DEC for CD, FB and CM than WM (0.84 [0.04, 1.65]; 0.91 [0.16, 1.66]; 1.08 [0.40, 1.08]) and for CM than FW (0.92 [0.05, 1.78])

Regarding efforts starting speeds, the technical drills elicited more ACC starting < 5 km·h^{-1} for WM and FW than CM (3.06 [0.23, 5.89], 3.67 [0.09, 7.25]), more ACC starting 10-15 km·h^{-1} for CM than CD, FB, WM and FW (0.45 [0.17, 0.74], 0.36 [0.10, 0.62], 0.48 [0.22, 0.74], 0.51 [0.18, 0.83]), more ACC starting 15-20 km·h^{-1} for FW than CD, FB, CM and WM (0.14 [0.10, 0.18], 0.13 [0.09, 0.17], 0.13 [0.10, 0.17], 0.11 [0.07, 0.14]), more ACC starting 20-25 km·h^{-1} for WM than CM (0.03 [0.01, 0.04]), more DEC starting < 5 km·h^{-1} for FB, WM and FW than CM (3.25 [0.27, 6.23], 3.83 [0.85, 6.81], 5.35 [1.58, 9.12]), more DEC starting 10-15 km·h^{-1} for CM than CD, WM and FW (0.80 [0.10, 1.49], 1.18 [0.55, 1.82], 1.12 [0.32, 1.93]), more DEC starting 15-20 km·h^{-1} for FB, CM, WM and FW than CD (0.20 [0.04, 0.37], 0.20 [0.05, 0.35], 0.18 [0.01, 0.34], 0.37 [0.17, 0.56]), more DEC starting 20-25 km·h^{-1} for WM than CD, FB, CM and FW (0.15 [0.08, 0.22], 0.13 [0.06, 0.19], 0.14 [0.08, 0.20], 0.11 [0.03, 0.19]).

Matches

Competition matches elicited more low ACC for CM than CD (1.74 [0.65, 2.82]), more moderate ACC for all positions than CD (FB: 0.31 [0.03, 0.58]; CM: 0.36 [0.12, 0.61]; WM: 0.44 [0.19, 0.07]; FW: 0.37 [0.06, 0.68]), more low DEC for FB and CM than WM (0.90 [0.07, 1.73], 0.91 [0.18, 1.64]), and more moderate DEC for CM than WM (0.24 [0.05, 0.43]).

Regarding efforts starting speed, matches elicited more ACC starting 5-10 km·h^{-1} for WM than CD (4.26 [1.04, 7.49]), more ACC starting 10-15 km·h^{-1} for CM and WM than CD (1.47 [0.36, 2.58], 1.43 [0.26, 2.59]), more ACC starting 15-20 km·h^{-1} for CM than CD (0.41 [0.04, 0.78]), more ACC starting 20-25 km·h^{-1} for FW than CD (0.13 [0.02, 0.24]), more DEC starting 5-10 km·h^{-1} for WM than CD (4.56 [0.49, 8.64], more DEC starting 10-15 km·h^{-1} for CM than CD (2.54 [0.67, 4.40]), more DEC starting 15-20 km·h^{-1} for CM than CD and FB (1.30 [0.50, 2.09], 0.83 [0.04, 1.63]), more DEC starting 20-25 km·h^{-1} for CM, WM and FW than CD (0.24 [0.01, 0.46], 0.42 [0.18, 0.66], 0.43 [0.15, 0.71], more DEC starting >25 km·h^{-1} for WM than CD and CM (0.10 [0.01, 0.20], 0.12 [0.04, 0.20]).

Discussion

The purpose of this study was threefold: to compare the ACC and DEC demands between different soccer drills and competitive matches; to compare the different drills; and to compare demands between playing positions. The main findings of this study were that different drills elicited different ACC and DEC demands, and matches imposed higher demands – especially in high intensities and in higher starting speeds – than any drill. In addition, more differences between playing positions were found during technical drills, SSG and matches, than rondos.

Regarding the comparison between the effort's intensity during matches and drills (Figure 20), competition elicited more high-intensity (> 75%) ACC and DEC than training drills, except during SSG (DEC). Interestingly, more ACC and DEC demands were previously reported to occur during SSG than during matches (194) which could seem contradictory to our findings. However, we found more low intensity (25-50%) ACC and DEC during SSG and during rondos, which could mean that matches only surpass these drills' demands in higher intensities. Moreover, according to our results, ACC and DEC intensities differed largely to very largely between efforts taking place during compensation exercises and matches. Martín-García et al. (69) reported higher ACC and DEC (> 3 $m \cdot s^{-2}$ and < -3 $m \cdot s^{-2}$) demands during compensations sessions than in other training sessions, but since the efforts starting speed was not reported, we cannot directly compare their results with our findings. The compensation drills were composed with high-speed running activities, which could lead players to reach higher speeds but less intense ACC and DEC. Considering our findings, SSG (4vs.4) could be a good strategy to compensate high intensity DEC to players with low or absent playing time. However, to compensate high intensity ACC, players would probably need to accelerate from high starting speeds, because ACC individual capacity decreases as the starting speed increases (24,219).

In our study, compensation drills imposed more ACC and DEC starting at velocities > 20 $km \cdot h^{-1}$ than any drill (Table 14) and matches - except DEC starting between 20-25 $km \cdot h^{-1}$ (unclear effect size) - (Figure 22). Nevertheless, both low and moderate (50-75%) occurrences and efforts starting at higher velocities were higher in all other drills than during compensation, which potentially means that compensation drill is indeed a better choice to compensate match demands to players that failed to participate during competition, or that competed for a reduced period of time. However, high-intensity DEC could need a different strategy, with SSG being a valid option to that goal, as this drill (in 4vs.4 format) appears to mimic peak match periods (237). However, could a drill that is played in small areas mimic match demands? According to our findings relative to efforts starting speed (Figure 21), it fails to do so. During SSG, players performed more ACC and DEC starting < 5 $km{\cdot}h^{-1}$ than during matches but performed less efforts > 5 $km{\cdot}h^{-1}$ in comparison with matches, similar to what we have registered in rondos drills. Due to space limitations, players found difficulties to achieve higher speeds in these drills than during matches and than during technical and compensation drills. Rondos drills are widely used in practice, but scarcely investigated. We found more low and moderate DEC during this drill than during compensation and technical drills, which means that this drill could lead players to higher knee joint' load than expected (20).

The differences between playing positions were mainly registered in low and moderate intensities efforts, and only during SSG and technical drills we observed differences in high intensity ACC (more efforts per minute performed by FB than CM, and by WM than CD respectively). This highlights the importance of analyzing efforts regarding players' individual capacities (24). Previous research has provided different demands for positions according to the used method. If the absolute threshold is used, studies report more efforts to wide positions such as FB and WM (194); however, if the relative method is used, previous research reported higher demands for central positions (204). Regarding the efforts starting speed, we found that wide positions performed more efforts starting at higher speeds (>20 $km{\cdot}h^{-1}$) during SSG and technical drills, while during matches, CD performed less efforts starting at higher speeds than all other playing positions.

Our study displays two major limitations: first, our findings relate only to one team, and other contexts can present different findings; secondly, drills' categorization is staff dependent, and different drills variables can elicit different demands (194). However, we analyzed a crucial - but scarce - topic to football training. Coaches should account for different demands according to different drills instead of exclusively focusing on sessions as one all. Moreover, replicating matches ACC and DEC demands with drills would be challenging, because differences can occur not only in efforts intensities but also how those efforts start.

Conclusions

Match elicited more high-intensity ACC and DEC than any drill, with more efforts starting at higher velocities. Regarding different drills, SSG elicited more high-intensity efforts, and compensation drills allowed players to perform more efforts from higher starting speeds. Differences between positions in high-intensity efforts were only found during SSG and technical drills, with wide positions performing more ACC than CD and CM. During these two drills, wide positions performed more efforts starting at higher speeds, while during matches, CD performed less efforts that started at higher speeds than any other playing position.

Practical Applications

The findings of this study can help practitioners prepare training sessions, while accounting for ACC and DEC demands. First, since matches elicited more high-intensity ACC and DEC than any drill, with more efforts starting at higher speeds, non-starters players may receive lower loads than starters during each microcycle. To compensate match demands, combining compensation drills and SSG provide high-intensity ACC and DEC, with high starting speeds. Secondly, since different drills, elicit different demands, practitioners should consider mixing exercises to avoid excessively high or low loads during one training session. Finally, players' positions also separate efforts demands, but using an individualize approach to calculate ACC and DEC demands, can help practitioners compare players.

4.7. Study VII (The impact of different warm-up strategies on acceleration and deceleration demands in highly-trained soccer players)

Citation: Silva H, Nakamura FY, Bajanca C, Pinho, G, Loturco I, Marcelino R. The impact of different warm-up strategies on acceleration and deceleration demands in highly-trained soccer players. (This study is currently under review by a scientific journal)

Abstract

The aim of this study was to compare the differences in acceleration and deceleration demands between three different warm-up strategies applied to highly-trained soccer players. Nineteen players were monitored for four weeks, using a 10 Hz GPS. Warm-ups were divided as: *Reaction speed* (speed exercises with reaction to a stimulus), *Run* (self-paced running) and *Speed* (exercises such as shuttle running or circuits). Accelerations and decelerations magnitudes were classified as low (25-50%), moderate (50-75%) and high (>75%) intensities. Additionally, efforts were analyzed according to their respective starting speeds (< 5 km·h^{-1}, 5-10 km·h^{-1}, 10-15 km·h^{-1}, 15-20 km·h^{-1}, 20-25 km·h^{-1}, >25 km·h^{-1}). Differences between warm-up strategies were estimated via paired mean differences along with effect sizes. Overall, the three warm-up strategies led to very few high-intensity efforts, especially in terms of high-intensity decelerations. Players performed more high-intensity efforts, and starting from higher starting speeds, during *Speed* warm-up, mainly when compared to the *Run* warm-up. The *Reaction Speed* warm-up led to more low and moderate intensity efforts per minute than the other two strategies. In summary, when selecting different warm-up strategies, practitioners should consider the main objective of the training session, because different warm-up strategies may lead to different physical demands and responses to those demands.

Keywords: athletic performance, football, sprint, training load, speed, team-sports.

Introduction

The warm-up (WU) is the first activity performed in soccer, before matches and training sessions. As the term suggests, WU is temperature-related and can be passive, by using external means to raise core and muscle temperature, or active, which involves specific drills that usually lead to greater benefits when compared to passive WU (238,239). Most WU effects, such as decreased stiffness, increased nerve-conduction rate, altered force-velocity relationship and increased lactic energy provision are temperature-related (238), and distinct WU protocols can be used to achieve a variety of physiological and neuromuscular changes. For example, a high-intensity WU can cause a greater increase in muscular temperature and induce post-activation performance enhancement for subsequent powerful actions (e.g., run, jump, or shoot). On the other hand, this may also lead to faster energy depletion, which may be a detrimental factor in high-performance sport settings (239,240).

Similarly, WU duration can also affect performance. One study (241) compared WUs in soccer players with different durations, founding improvements in sprint performance in the shorter protocol (8 minutes), whereas the longer protocol (25 minutes) induced a decrease in acceleration (ACC) capacity. The benefits of shorter protocols were also discussed in another study, with the authors highlighting their time-efficiency when reporting no changes in repeated-sprint performance after shorter or longer protocols (242).

However, the common practice among soccer practitioners appears to be distant from this evidence. For instance, using a survey of Premier League and Championship clubs, Towlson et al. (243) reported that 89% of practitioners applied WUs with durations equal or longer than 25 minutes. Moreover, a current Premier League club WU protocol of about 23 min had no positive effects on performance when compared with two different protocols (i.e., 3 vs. 3 small-sided games, and 5 maximal repetitions in leg press) (244). Overall, WUs prior to soccer matches usually include running and mobility exercises, and certain sport-specific drills such as small-sided games, lasting around 30 minutes (245). Somewhat surprisingly, stretching - static or dynamic - is also commonly prescribed in WUs, even considering the negative effects of static stretching on athletic performance (246–248).

Injury prevention is another point of concern in the prescription of WUs, an issue that has been widely discussed in the scientific literature (249–251). For this purpose, for example, the FIFA Medical and Research Centre ("F-MARC") developed the FIFA 11+

WU program, a "standard" WU protocol of 20-25 minutes that comprises running, strength, plyometric, and balance exercises and combines cardiovascular activation and neuromuscular stimuli within the same session in an attempt to reduce and mitigate the risk of non-contact injuries in soccer players (246). Indeed, it has been observed that the implementation of FIFA 11+ as a regular practice can help to reduce the injury risk (252,253) while, at the same time, can induce positive responses capable of subsequently improving soccer-specific performance (254).

Notwithstanding the selected WU strategy, scientific research has only focused on its effects on injuries and performance. On the other hand, training and matches have been receiving increasing attention from practitioners and researchers, specifically in relation to the load imposed to soccer players when performing these activities. This load is defined as "training load" (56) and its monitoring can be a valuable tool to assist coaches in designing safer and more effective training programs (59). Among a number of training load-derived metrics (e.g., running intensity, total distance, rating of perceived exertion, and heart rate variables), ACC and deceleration (DEC) emerge as some of the most frequently used training load variables for soccer training monitoring, as revealed by a survey of 82 professional soccer clubs (3). Notably, players with higher ACC capacity tend to jump higher and sprint faster over linear and multilinear trajectories (235). Finally, the influence of ACC and DEC events on post-match muscle damage markers, performance indicators (e.g., changes in vertical jump power output), and muscle soreness has also been investigated, with interesting results in terms of correlations (e.g., evidence of moderate correlations between high accelerations and decelerations and muscle damage markers) (188).

Based on the above reasoning, monitoring ACC and DEC demands across different WU strategies, commonly prescribed before soccer-specific training sessions and matches, may be extremely relevant from a practical perspective. To the best of our knowledge, this has not been previously investigated. Therefore, the purpose of this study was to compare the ACC and DEC demands of soccer players according to their playing positions, during different WU strategies.

Methods

Experimental Approach to the Problem

Players used GPS equipment as required for training routine monitoring and accepted data sharing for research purposes. For this reason, Ethics Committee clearance was not required (48). Nevertheless, written consent was obtained by the coaching staff. Collected data was not filtered by the equipment software, and each player was analyzed individually. From velocity and time data, we computed the ACC and DEC demands and the time spent in these tasks for the relative count (i.e., number of efforts per minute). We also collected the starting speed of each effort, for both ACC and DEC events.

Subjects

Data were obtained from one team playing in the Portuguese U23 League (Revelation League) across 19 training sessions (full mesocycle). The participants were 33 team members, classified as "highly-trained subjects" (i.e., team-sport athletes competing in national or state tournaments) (44). However, players who did not participate in a minimum of 50% of training sessions, independently of the reason, were excluded. Additionally, since the goalkeepers' routine was specific to their position, these athletes were also excluded from the analysis. A total of 19 players (20.1 ± 1.2 years; 179.9 ± 4.5 cm) were included in the study. Players were divided according to their playing' positions, as follows: 3 central defenders (CD), 4 fullbacks (FB), 6 central midfielders (CM), 4 wide midfielders (WM) and 2 forwards (FW).

Procedures

WUs were divided into three different strategies, as previously defined by the coaching staff, without any interference or adaptation for research purposes. WUs were performed before 19 different soccer-specific training sessions, with all players completing the same WU in the same day. WU strategies were: (1) *reaction speed WU* (8-15 min; performed during sessions the day before the match): after activation drills, players performed high-speed drills with players competing with each other, where players needed to react as quick as possible after a given stimulus; (2) *run WU* (9-14 min; performed during sessions the day after the match): after activation drills, players ran at low-intensity speeds, in a self-selected pace, but with instructions to avoid high speeds; (3) *speed WU* (14-20 min; performed during sessions two days before the match): after activation drills, players performed high-intensity drills, such as shuttle runs or circuits, organized in competitive and non-competitive formats, focusing on acceleration, deceleration, and speed efforts, preparing players for the following drills (with players aiming to achieve > 90% maximal speed). Players were required to perform the different WUs without pausing to rest or drink fluids. No specific motivation or feedback was provided to players in any of the tested strategies.

GPS units (Catapult S7; Catapult Sports, Melbourne, Australia) sampling at 10 Hz were used to track players during the WU sessions. The GPS unit was placed on the upper middle back, between the scapulae of the player, using the special protective vests recommended by the manufacturer. This equipment is a certified FIFA Electronic Performance and Tracking System (190). Each effort was counted from the start of the speed increase or decrease until the change in speed reached 0 $m \cdot s^{-2}$ (218). ACC and DEC intensities were established relative to the maximal effort registered during the mesocycle by each player, based on the "percentage intensity approach" (219) adapted from the method proposed by Sonderegger et al. (24), at 25-50% (low intensity), 50-75% (moderate intensity) and > 75% (high intensity). To determine the maximal effort, we collected the highest ACC and DEC values of the mesocycle of each player, excluding isolated values (two efforts must have occurred in the same $m \cdot s^{-2}$ bandwidth interval). For example, if the maximal ACC value was 7.30 $m \cdot s^{-2}$, another value between 7-8 $m \cdot s^{-2}$ had to exist for this value to be considered as "maximal". Additionally, the starting speed of each ACC and DEC event was also collected according to bandwidth intervals: (< 5 $km \cdot h^{-1}$, 5-10 $km \cdot h^{-1}$, 10-15 $km \cdot h^{-1}$, 15-20 $km \cdot h^{-1}$, 20-25 $km \cdot h^{-1}$, >25 $km \cdot h^{-1}$) (219). Number of efforts per minute that occurred during each WU strategy were counted according to their intensity and starting speed.

Statistical analysis

Mean ± standard deviation were calculated for all analyzed variables, including the multiple ACC and DEC intensities, and starting speed intervals. Paired mean differences were computed with the Jamovi software (Version 2.3.19.0; JAMOVI project, 2022) using the ESCI package (192,193). Two different measures were analyzed separately: the number of efforts of one player during each WU condition was compared to the number of efforts of the same player in the remaining conditions. This procedure was conducted for each effort during the respective WUs and for the different ACC and DEC intensities and starting speed intervals. Effect sizes were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). If the CI crossed zero, an unclear effect size was established (55). Playing positions were compared on number of ACC and DEC per minute, according to the WU protocol. Differences were analyzed with independent group contrasts, with 90% CI, also using the ESCI package (192,193). If the 90% CI crossed zero, differences were considered unclear.

Results

Figure 23 (data available at Table S6 in Supplementary Information) presents mean ± SD of number of efforts per minute according to their respective intensities. The *Reaction speed WU* elicited more efforts than the others WU strategies at low and moderate intensities. Less than 1 effort per minute were registered at moderate and high intensities, and more ACC were registered than DEC, except high-intensity DEC during the *Run WU*.

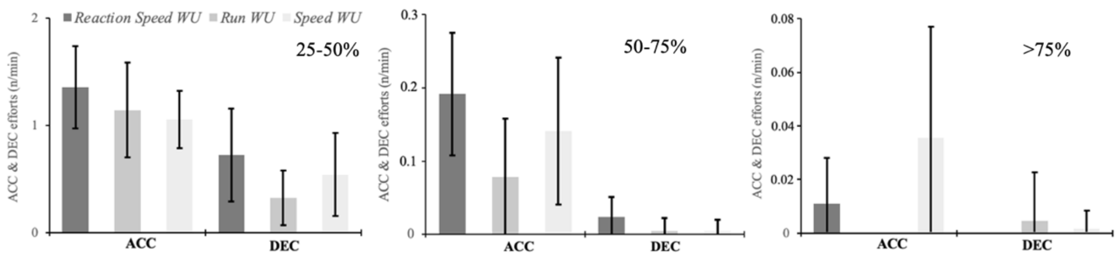

Figure 23. Mean ± SD of accelerations and decelerations per minute for each WU strategy during distinct intensity intervals. ACC=acceleration; DEC=deceleration; WU=Warm-up.

Figure 24 (data available at Table S7 in Supplementary Information) presents mean ± SD of the number of efforts per minute according to starting speed intervals. Efforts that started at higher speeds (> 20 km·h^{-1}) occurred almost exclusively during the *Speed WU*.

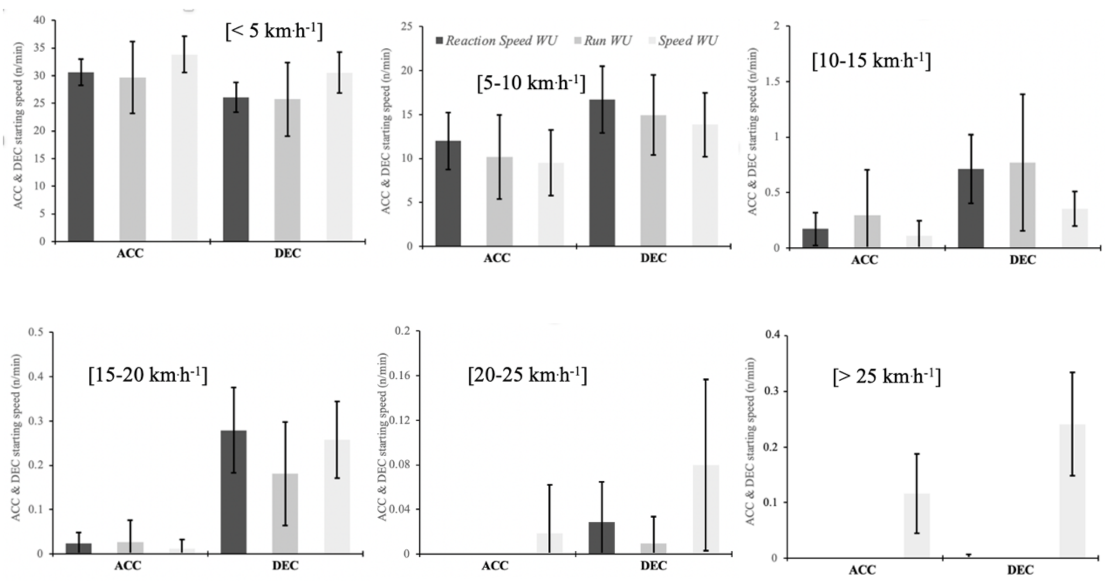

Figure 24. Mean ± SD of accelerations and decelerations per minute according to the starting speed (< 5 km·h^{-1}, 5-10 km·h^{-1}, 10-15 km·h^{-1}, 15-20 km·h^{-1}, 20-25 km·h^{-1} and > 25 km·h^{-1}) of each effort during different. ACC=acceleration; DEC=deceleration; WU=Warm-up.

Figure 25 (data available at Table S8 in Supplementary Information) presents the effect sizes found in paired mean differences between WU strategies. CI can be asymmetrical as the upper margin of error can be smaller or larger than the lower margin error (53). Effect sizes are displayed for efforts intensities and efforts starting speed.

Effort intensity

Players performed more low and moderate ACC (ES: 0.49 [0.02, 1.01]; ES: 1.29 [0.72, 1.29], respectively) and DEC efforts (ES: 0.74 [0.45, 1.11]; ES: 0.64 [0.04, 1.32], respectively) during the *Reaction WU* than during the *Run WU*. Players performed more low ACC and DEC efforts (ES: 0.94 [0.60, 1.36]; ES: 0.33 [0.13, 0.56], respectively), and more moderate DEC efforts (ES: 0.89 [0.37, 1.50]) during the *Reaction WU* than during the *Speed WU*. Players performed more high ACC efforts (ES: 0.74 [0.21, 1.33]) during the *Speed WU* than during the *Reaction WU*; and more low DEC efforts (ES: 0.42 [0.15, 0.74]) during the *Speed WU* than during the *Run WU*.

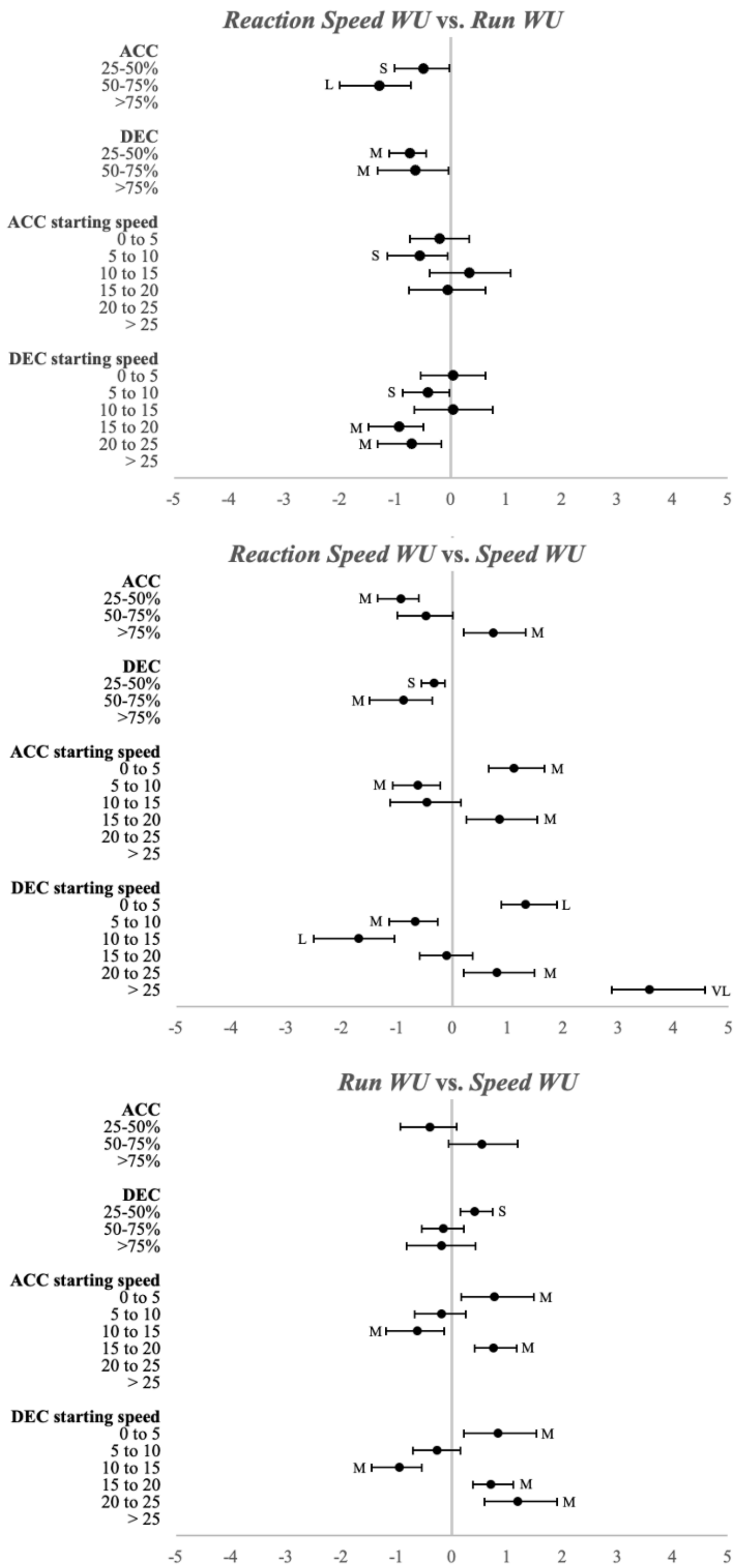

Figure 25. Effect Sizes (with 90% Confidence Interval) of the mean differences between accelerations and decelerations per minute according to respective intensity percentage and starting speed ($km \cdot h^{-1}$) intervals. ACC=acceleration; DEC=deceleration; WU=warm-up. VL=very large effect size (2.0<4.0); L=large effect size (1.2<2.0); M=moderate effect size (0.6<1.2); S=small effect size (0.2<0.6); T=trivial effect size (<0.2). Note: no comparison is available if no effort is registered in a specific interval.

Effort starting speed

More ACC events were registered during the *Reaction WU* than during the *Run WU* at (starting speed of) 5-10 km·h^{-1} (ES: 0.56 [0.05, 1.14]). More DEC events were registered during the *Reaction WU* than during the *Run WU* at 5-10 km·h^{-1} (ES: 0.42 [0.03, 0.87]), 15-20 km·h^{-1} (ES: 0.93 [0.49, 1.48]) and 20-25 km·h^{-1} (ES: 0.70 [0.17, 1.32]). More ACC events were registered during the *Reaction WU* than during the *Speed WU* at 5-10 km·h^{-1} (ES: 0.62 [0.21, 1.08]). More DEC events were registered during the *Reaction WU* than during the *Speed WU* at 5-10 km·h^{-1} (ES: 0.67 [0.27, 1.14]) and 10-15 km·h^{-1} (ES: 1.70 [1.05, 2.51]). More ACC events were registered during the *Speed WU* than during the *Run WU* at 0-5 km·h^{-1} (ES: 0.78 [0.17, 1.48]) and 15-20 km·h^{-1} (ES: 0.76 [0.42, 1.18]). More DEC events were registered during the *Speed WU* than during the *Run WU* at 0-5 km·h^{-1} (ES: 0.83 [0.22, 1.54]), 15-20 km·h^{-1} (ES: 0.71 [0.39, 1.11]) and 20-25 km·h^{-1} (ES: 1.19 [0.59, 1.91]). More ACC and DEC events were registered during the *Run WU* than during the *Speed WU* at 10-15 km·h^{-1} (ES: 0.63 [0.13, 1.20]; ES: 0.95 [0.54, 1.46] respectively).

Playing Positions

Differences between playing positions were only found in the *Run WU*, with CM (11.2 [2.31, 20.09]) performing more ACC and WM (10.81 [1.52, 20.10], 10.42 [0.63, 20.20]) performing more ACC and DEC events per minute than FB.

Discussion

The purpose of this study was to assess and compare the ACC and DEC demands imposed by three distinct WU strategies in highly-trained soccer players according to their playing positions. Overall, across all conditions, we observed that efforts with lower intensities occurred more frequently than efforts with higher intensities, similar to what has been systematically reported for soccer-specific training sessions (194). Specifically, the *Speed WU* (the WU activity with the longest duration [14-20 min] among the four WU strategies) elicited, on average, at least one high-intensity effort (ACC) per session and led to a greater number of efforts starting at higher speeds. The lowest demands were clearly observed in the *Run WU*, where no high-intensity ACC, or any effort above 25 $km \cdot h^{-1}$ occurred.

Our findings present a novel alternative to training monitoring that assesses training sessions as a whole. In fact, when monitoring training load, sport scientists usually consider the demands occurred during the entire training session (categorized according to the distance in days to the match-day) and not the demands of each training session drill or section (255). However, this strategy potentially underestimate warm-up loads due to the reduced time spent in this activity in comparison to the rest of the training session. This is important, because load differences between specific-soccer exercises exist (194), including between WU and other soccer-activities (e.g., matches, small-sided games, technical-tactical exercises, etc.), as showed by Ramos and colleagues (34) in female soccer players. Therefore, sport scientists are encouraged to monitor training activities independently, also considering the relation between activities in addition to the relation between consecutive training sessions (2,3). Finally, the lack of significant differences between distinct playing positions may be explained by the fact that all players performed the same activities; hence, the differences found during the *Run WU* are probably associated with inter-subject variability in self-selected pace.

If practitioners select the *Speed WU*, higher demands may be expected, especially for efforts starting at speeds > 20 $km \cdot h^{-1}$. Since this exercise is characterized by intense movements such as shuttle runs, players will potentially achieve higher running speeds, which consequently leads to more intense ACC and DEC events. Indeed, shuttle running was previously compared to 1vs.1 small-sided game with same duration, eliciting fewer ACC and DEC events > 3 $m \cdot s^{-2}$, but with higher distance covered at speeds > 25.2 $km \cdot h^{-1}$ (compared to the game format) (22). However, when compared to a small sided game that included a higher number of players (6 vs. 6), shuttle running led to more time spent in ACC and DEC efforts (> 1.5 $m.s^{-2}$, > 2.5 $m.s^{-2}$, and > 3.5 $m.s^{-2}$) (256). In summary, among all tested WUs, the *Speed WU* was the strategy where players reached higher speeds and where more high-intensity efforts occurred; therefore, this strategy should be avoided during training sessions close to competition in order not to compromise match preparedness and/or recovery between successive matches (255). Due to its high intensity, the *Speed WU* may increase substantially energy depletion (256); nonetheless, with adequate recovery and appropriate prescription (e.g., short duration), this WU strategy can also be used to acutely improve physical performance in training and competition (239).

The *Reaction Speed WU* elicited more low and moderate intensity ACC and DEC events per minute than the other two WU strategies. Regarding starting speed intervals, the *Reaction Speed WU* led to more ACC efforts starting between 5-10 $km \cdot h^{-1}$ and between 15-20 $km \cdot h^{-1}$. Generally speaking, during this type of WU, players perform more high-intensity ACC actions than in the other two WUs. However, the data obtained during the *Speed WU* highlight the role played by movement repetition in training load. Although the *Reaction Speed WU* increased the relative frequency of high-intensity ACC efforts, this WU strategy prioritizes players' reaction. In this regard, the rest between successive efforts during the *Reaction Speed WU* is longer than, for example, during the *Speed WU*. In fact, in the *Reaction Speed WU*, after performing a very intense effort in response to a given stimulus, players returned to their previous position slowly, in order to allow adequate recovery. In contrast, during shuttle drills, players are usually requested to quickly return to their previous (initial) position. Since directional changes increased the time spent in ACC maneuvers (257), this quick return to "the base-line" could be one of the major reasons to justify the difference in physical demands.

As expected, the *Run WU* was the least demanding WU among all analyzed strategies. Interestingly, during the *Run WU*, we observed more efforts occurring between 10-15 $km \cdot h^{-1}$ than during the *Speed WU*, which means that players performed this activity predominantly within this respective speed range. Straight running at constant and comfortable speed will certainly result in lower muscular and metabolic costs (e.g., oxygen consumption) as compared to more intense and sport-specific activities, such as linear and/or multidirectional sprints (258). For this reason, this type of activity is commonly used not only as a WU routine, but also as a recovery strategy for soccer players (259).

Since different workout durations affect players in a different way (241), distinct WU strategies should also receive attention from practitioners and researchers. Even if the main goal of WU is to prepare athletes for the following activities (i.e., training session or match), previous research recommended progressively increases in intensity until maximal efforts occur close to the end of the WU (246). Under this perspective, WU can also help athletes improve (or at least maintain) their physical performance during the competitive season. At first glance, implementing shuttle run or reaction speed drills may concern coaches, who might believe that those drills could increase the risk of injury and level of fatigue. However, a solid body of evidence confirms the effectiveness of intense WU routines in acutely improving physical performance (245,260) and reducing the risk of injury (261). Interestingly, soccer players that covered higher distances in high-speed running (> 14.4 $km \cdot h^{-1}$) and sprinting (> 19.8 $km \cdot h^{-1}$) were at reduced non-contact injury risk than their counterparts (262) probably because these players are better prepared to cope with match demands (263). Moreover, exposing players to chronic higher loads may be crucial to ensure their fitness preparedness, minimizing the non-contact injury risk, as long as that exposure occurs without sudden and excessive load spikes (8). Thus, warm-up is a part of training that can have positive chronic effects on football players, and this will probably depend on the characteristics of each warm-up session.

Our findings present a step towards understanding the effects of certain WU strategies on training load and potential training adaptations. First, we compared the ACC and DEC demands of different, but commonly used, WU strategies; and second, we compared these demands between different playing positions. This study presents two major limitations: (a) these results refer to a particular soccer team, with a particular coaching staff, responsible for prescribing and monitoring WU activities; therefore, the extrapolation of our findings to other populations (including soccer clubs) should be made with caution; (b) the investigated WUs are inserted into distinct strategies, thus, they do not have a fixed or programmed structure as, for example, the "FIFA 11+", which compromises the replication of this research and the prescription of these strategies.

Conclusions

All WU strategies led to very few high-intensity efforts, especially high-intensity DEC. Additionally, the different WU strategies elicited different demands, highlighting the importance of considering and examining WU activities in a separate way. During the *Speed WU*, players achieved higher speeds, which resulted in a higher number and frequency of high intensity efforts and, therefore, of intense ACC and DEC. These differences were even more pronounced when compared to the *Run WU*, which was found to be the least demanding WU routine among the three analyzed strategies. The *Reaction Speed WU* led to more low and moderate intensity ACC and DEC events per minute than the other two WU strategies, a fact that can be easily explained by considering the longer intervals (and adequate recovery) typically provided during "reactive drills". Future studies are needed to test and compare the effects of using different WU strategies under similar training and competitive conditions.

Practical Applications	Coaching staff should be aware that WU can play a critical role in promoting training responses and adaptations. When selecting different WU strategies, practitioners should always consider the main objective of the training session. For example, before technical-tactical training sessions where rapid responses and reactions are expected, the *Reaction Speed WU* may be applied. In contrast, prior to high-intensity sessions, where a higher number of intense ACC and DEC efforts usually occur, the *Speed WU* may be used to prepare players more specifically for these complex demands. The *Run WU* seems to be more indicated for preparing players for longer and/or moderate training sessions or even as a re-warm-up strategy to be adopted during official soccer matches. Irrespective of the WU strategy selected, it is essential to monitor the starting speed of repeated efforts, as it has a crucial impact on ACC and DEC demands. Finally, coaches should consider that WU routines, either acutely or chronically, could potentially affect training load and, therefore, must be assessed and analyzed separately.

4.8. Study VIII (Match peak speeds, and maximum accelerations and decelerations differ in young soccer players: expression of maximal capacities is dependent of match context)

Citation: Silva H, Nakamura FY, Casamichana D, Barba E, Castellano J, Marcelino, R. Match peak speeds, and maximum accelerations and decelerations differ in young football players: expression of maximal capacities is dependent of match context**.** (This study is currently under review by a scientific journal)

Abstract

This study aimed to compare peak speeds and maximal accelerations and decelerations during football matches among young players divided into age-categories (U15, U17, U19 and U21, under 15, 17, 19 and 21 years old, respectively) and playing positions. Maximal values were collected during competition, as standard player's load monitoring with global positioning system. Field tests (0-30 meters and 0-5 meters) were performed to assess differences between age groups' maximal speeds and acceleration capacities. Independent mean differences were estimated with effect sizes to compare age groups and independent group contrasts to compare positional differences. Differences between U17 and U19 groups during matches were unclear, but both groups reached higher peak speeds, maximal accelerations, and maximal decelerations than U15 (moderate and small effect sizes) and U21 groups (moderate and effect sizes). U15 reached higher maximal accelerations than U21 (small effect size). Forwards and wide midfielders achieved higher peak speeds, maximal accelerations, and maximal decelerations than central midfielders and central defenders. Field tests may show players' capacities but can potentially fail to portrait how players demonstrate their capacities during competition. Football coaches can use this information to better prepare their tactical approach considering competition possibilities to achieve higher speeds, accelerations, and decelerations for age group and playing positions.

Keywords: age, competition, physical capability, speed, sprint

Introduction

During competition, football players need to quickly perform several actions (technical or physical) to gain advantage to opposition. A goal opportunity can emerge if one player reaches the ball or a space before the opponent. This constant urgency of quickness will probably increase with tactics that potentiate high-intensity pressing, exposing players to multiple short but intense accelerations, decelerations, and high-speed running efforts (6). Barnes et al. (264) compared physical performances in the English Premier League across seven seasons (2006/07 to 2012/13) and reported an increase in high-intensity running (19.8–25.1 $km{\cdot}h^{-1}$) and sprinting (> 25.1 $km{\cdot}h^{-1}$) covered distances by 30-35%. This means that young football players will probably need to sustain an increase in these efforts over the years. Moreover, achieving higher speeds can also affect the player's individual success. Even though successful and unsuccessful teams present similar maximum running speeds (265), higher speeds were found in starters in contrast to non-starters (266).

Maximum speeds are usually assessed by two methods: testing and monitoring. The first method implies applying a specific protocol, where players usually start from a stand position and try to achieve their maximal speed when passing through photocells (time gate), and more than one trial is required (267). Despite probably being the most used method in research, this method presents two main issues: first, implementation in elite contexts may be difficult (202); and second, they lack reality, being that from the standing start or by placing players in a controlled environment to perform their best. However, competition is different. For example, professional and amateur players perform similarly during maximal speed tests but differ on matches maximal speeds (professionals achieved 91.6 % of their test result, while amateurs achieved only 92.5%) (206). As so, the second method can correct this by using maximum values obtained from match (or training) context through global positioning system (GNSS and GPS). Two studies compared the two methods, reporting large correlation between them (205,268). The second method provides an additional advantage, i.e., the possibility of easily assessing acceleration and deceleration. Field testing of acceleration can also be applied, with the same limitations inherent to speed tests, but testing maximal voluntary deceleration is much more complex. Deceleration capabilities were usually assessed with change of direction tests, where athletes are required to quickly reduce their speed and redirect their trajectory (269). However, the deceleration requirements during these tests are angle dependent, with athletes performing longer deceleration distances for 90º cuts than for 45º cuts (10). Recently, Harper et al. (203). assessed maximal deceleration using an acceleration-deceleration test, where athletes accelerated through 20 meters, and then performed a maximal deceleration and backpedaling to the 20 meters line (where deceleration started). Despite being an interesting approach, the usage of radar technology in football clubs is still scarce.

Knowing maximal speeds, acceleration, and deceleration, can provide interesting information for coaching staffs in the Academies. For instance, faster (10- and 30-meters sprint tests) young players (U15) performed higher distances at high speeds (> 14 $km{\cdot}h^{-1}$) during small-sided games (270). Additionally, sprint tests can help differentiating players between elite and non-elite young players (U13-U16) (271). Alongside playing level and performance during drills, comparisons between players' ages also showed differences, with younger players (U15) being faster than older players (U17) in very short distances (<5 m) (272). However, maximal speeds, assessed during small-sided games, were similar between age groups (U17, U19 and senior) (145). Hence, it would be important to know if maximal speeds, acceleration, and deceleration differ between age groups, considering the real competition scenario, which can elicit greater mechanical demands than small-sided games. Therefore, the purpose of this study is to compare maximal speeds, acceleration, and deceleration of young players during competition, according to their age and playing position.

Methods

Design

A cross-sectional comparative study was conducted to compare potential differences in speed, acceleration, and deceleration capacities of young male football players from the same elite Spanish club, playing in the first division for their respective ages.

Subjects

Seventy-eight players were monitored during 84 matches. Detailed data is presented in Table 16. The players were separated according to the age team: under 15 years old (U15), under 17 years (U17), under 19 years (U19) and under 21 years (U21).

Besides matches data, players were also assessed in two field tests: 0-30 meters to assess maximal speed; 0-5 meters to assess maximal acceleration Besides pooling players by age category, coaching staff divided players according to their playing' position as central defender (CD), fullback (FB), central midfielder (CM), wide midfielder (WM) and forward (FW). Only data from players that participated in matches were collected, but some players did not perform the field tests (U15: 2 out of 25 players; U17: 5 out of 17; U19: 4 out of 19; U2: 3 out of 17).

Table 16. Descriptive sample data divided by teams. Number of matches are presented as total matches and range of matches played by an individual player. Age, heigh and weight are presented as mean ± SD.

Teams	Players (*n*)	Matches (*n*) (range)	Age (years)	Height (cm)	Weight (kg)
U15	25	32 (1-14)	14.9±0.4	171.4±7.9	59.5±9.3
U17	17	16 (1-12)	16.7±0.5	176.7±7.7	68.7±7.5
U19	19	18 (1-14)	18.1±0.6	178.6±6.2	70.4±6.4
U21	17	18 (1-14)	19.4±2.5	180.0±6.7	73.5±6.2

U15=under 15 years old; U17=under 17 years old; U19=under 19 years old; U21=under 21 years old.

Monitoring

Maximal speed ($km \cdot h^{-1}$), acceleration and deceleration ($m \cdot s^{-2}$) values were retrieved as the maximal event recorded for each player. Matches per group are presented in Table 17. All teams played with 1-4-3-3 system with high pressure. Data was only considered if a player completed the match.

Testing

Besides matches data, to investigate if capacities or matches influence the most players' performance, players were also assessed in two field tests, assessing the time taken to complete the specific distance: 0-30 meters to assess maximal speed and 0-5 meters to assess maximal acceleration (Figure 2). Photocells WITTY (Microgate, Italy) were used to assess time, by placing them at the start (0 meters) and the end (5 and 30 meters) of the test. The timer started and stopped counting when the player crossed between the start and finish photocells respectively.

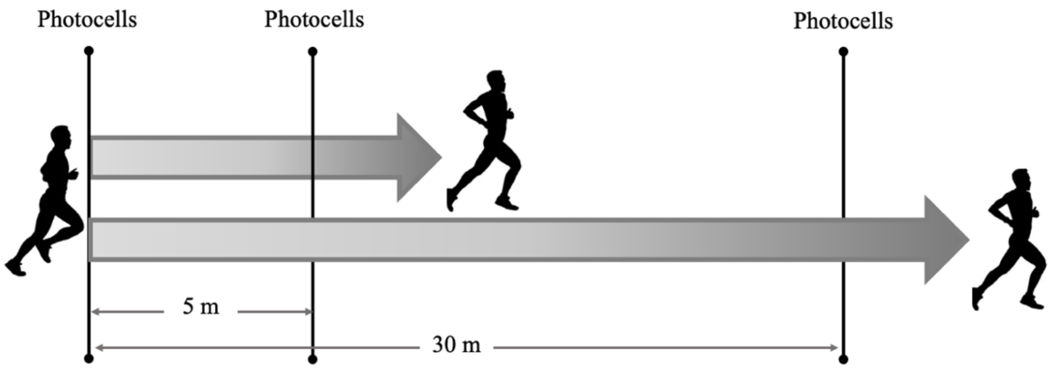

Figure 26. Maximal speed (0-30 meters) and maximal acceleration (0-5 meters) field tests

Procedures

Different age teams were monitored during competition matches with the same Global Positioning System (GPS). The external training load was collected using a 10-Hz GPS that integrated a 100-Hz triaxial accelerometer GPS devices (WIMU PRO, Realtrack Systems SL, Almeria, Spain). This technology has been previously used in football research on activity-demand profiles (45) and reported high levels of validity and reliability (273). Players wore the GPS devices from the beginning of the session until the end. The GPS device was fitted to the upper back (i.e., between the shoulder blades) of each player in a specifically designed neoprene harness to minimize movement artefacts. After each session, GPS data were downloaded using the specific software package (sPRO V.980, Realtrack Systems SL, Almería, Spain) on a personal computer and exported for further analysis.

Statistical analysis

Mean ± SD was calculated for each age group for maximal speed, and maximal acceleration and deceleration. Independent mean differences were estimated in Jamovi with ESCI package (192,193). All age groups were composed with only one team with two-year interval (U17: 15<17; U19: 17<19; U21: 19<21), except U15 that comprised two different teams with one-year interval each (U15: 13-14 and 14-15). Effect sizes were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). Unclear effect size was noted when CI crossed both positive and negative values (55). Independent groups contrasts were estimated with ESCI, with 90% CI, in Jamovi with ESCI package (192,193). Each position was compared to all others, and the first group was classified as reference group, and the second group classified as the comparison group. If the CI crossed both the positive and negative values, no difference between positions was reported.

Results

Maximal speeds, accelerations and decelerations are presented in Table 17. Maximal values assessed during matches are presented as $km{\cdot}h^{-1}$ (speed) and $m{\cdot}s^{-2}$ (accelerations and decelerations), while field tests' values are presented as seconds. U17 and U19 were the fastest groups during matches, but field tests performance increased with age.

Table 17. Table 2 Mean ± SD of maximal speed (during matches and field test), maximal acceleration (during matches and field test) and maximal deceleration during matches for each age group.

	Maximal speed		Maximal acceleration		Maximal deceleration
Teams	**match ($Km{\cdot}h^{-1}$)**	**test (seconds)**	**match ($m{\cdot}s^{-2}$)**	**test (seconds)**	**match ($m{\cdot}s^{-2}$)**
U15	28.31±1.91	4.47±0.22	4.75±0.47	1.04±0.04	-5.83±0.60
U17	29.49±1.66	4.21±0.08	4.89±0.38	1.04±0.03	-6.23±0.55
U19	29.70±1.70	4.20±0.11	4.87±0.38	0.99±0.03	-6.14±0.62
U21	29.34±1.76	4.15±0.10	4.64±0.50	0.97±0.04	-5.78±0.62

Note: U15=under 15 yr; U17=under 17 yr; U19=under 19 yr; U21=under 21 yr.

Effect sizes of differences between age groups for maximal speeds, decelerations during matches are presented in Figure 26 (data available at Table S9 in Supplementary

Information). U15 age group reached lower maximal speeds than U17 (ES [90% CI]: 0.65 [0.40-0.92]), U19 (ES: 0.77 [0.52-1.03]) and U21 (ES: 0.56 [0.32-0.81]). Differences in maximal speeds between U17, U19 and U21 were unclear (90% CI crossed both positive and negative values). U15 age group achieved lower maximal acceleration magnitudes than U17 (ES: 0.32 [0.06-0.58]) and U19 (ES: 0.27 [0.03-0.52]), but higher than U21 (ES: 0.08 [0.00-0.48]. As in maximal speed, comparisons of maximal acceleration between U17, U19 and U21 age groups were unclear. Finally, U15 age group achieved lower maximal deceleration magnitudes than U17 (ES: 0.71 [0.45-0.98]) and U19 (ES: 0.51 [0.27-0.76]), but higher than U21 (ES: 0.08 [0.16-0.32]). U21 age group reached higher maximal decelerations than U17 (ES: 0.77 [0.47-1.09) and U19 (ES: 0.58 [0.30-0.88]). Difference between U17 and U19 was unclear.

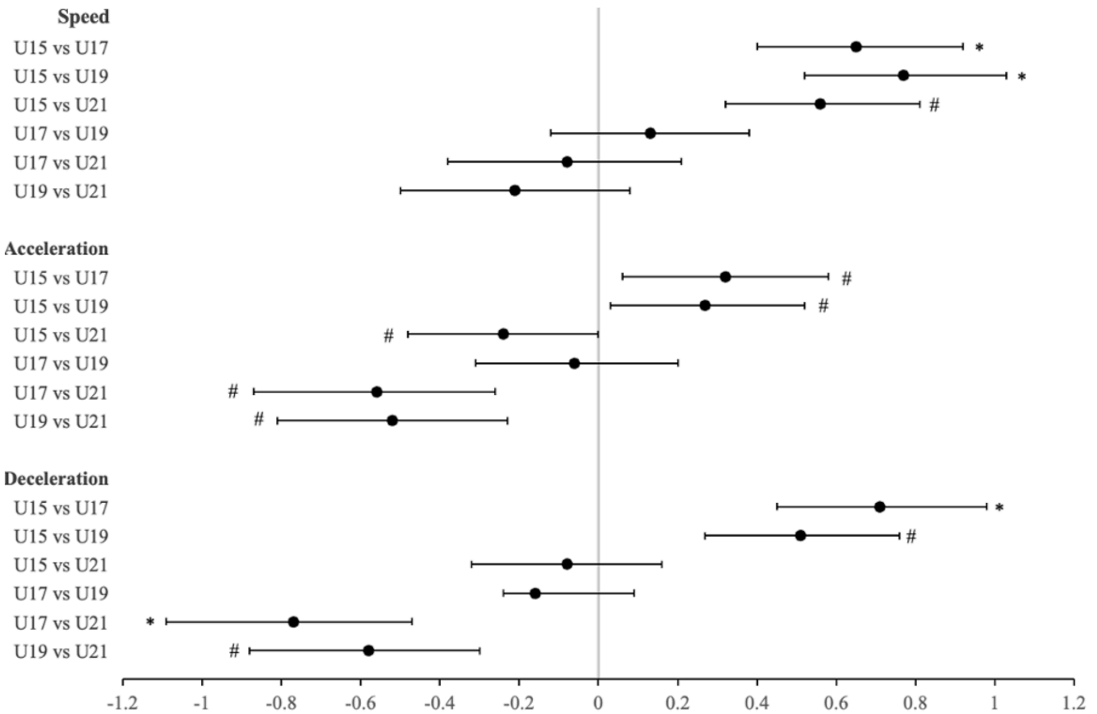

Figure 27. Standardized mean difference (90% CI) between age groups for maximal speeds (km·h^{-1}), accelerations (m·s^{-2}) and decelerations (m·s^{-2}). U15=under 15 years old; U17=under 17 years old; U19=under 19 years old; U21=under 21 years old.*moderate effect size (0.2-0.6); #small effect size (< 0.2).

Discussion

The purpose of this study was to compare maximal speeds, accelerations, and decelerations of young football players during competition, according to their age. We found differences between ages in speed, acceleration, and deceleration, with U17 and U19 players presenting higher speeds, accelerations, and decelerations than U15 and U21. However, these differences were not replicated on field tests performances.

Regarding match peak speeds, U15 achieved lower values than older players with moderate (U17 and U19) and small (U21) effect sizes (Figure 26). Interpreting these findings should comprise two main aspects: maximal speeds achievable during matches could relate to players' capabilities and context possibilities. Previous research stated that faster players achieve higher speeds during matches but matches elicit players to perform several short and intense efforts which can limit the possibility to achieve real maximal velocities (274,275). Our findings relate to those reported in previous studies, where maximal speed increased with age except from U20 to senior players (272,276). We also found similarities between speeds and accelerations and decelerations results, with U17 (moderate ES) and U19 (small ES) achieving higher maximal accelerations and decelerations than their younger (U15) and older (U21) counterparts. Interestingly, U15 achieved higher maximal acceleration than U21 (small ES). Previously research found different match demands in different age groups, reporting more accelerations and decelerations per minute executed by U19 players than by senior and U17 players (171). This could mean that older players face higher limitations during matches to reach higher speeds than younger players, which makes sense because it is expected that specialization and tactical knowledge increase throughout senior competition.

Another important consideration regards field tests. As players fail to replicate field tests performances, using field tests values to assess match physiological performances may be unfair to players. As demonstrated by our findings, the U21 outperformed the other age groups during field tests, but U17 and U19 achieved higher speeds and accelerations and decelerations magnitudes during matches. Field tests may be crucial to identify players capacities and monitor their development but using match maximum efforts could be more proficient to categorize efforts intensities during matches (205,268).

The differences between match and test performances have been established (206), but match performances are also influenced by tactical approaches – from the analyzed team and from opposition. As so, future research should investigate more teams, especially teams that play against each other, to understand the impact of tactical approaches on physiological performances. Nevertheless, this analysis can also be performed by each team staff to identify opportunities or limitations to players express the maximum capacities.

These findings represent an important information for coaches, which could better prepare their tactical approach to matches, by taking advantage of matches characteristics. According to our results, U17 and U19 matches facilitate players' expression of their speeds, accelerations and decelerations maximum capacities, so coaches could train situations to explore those possibilities. However, developing players' capabilities is extremely important, even if matches limit players' expression of their maximal capabilities. For instance, small-sided games can increase the exposure of players to intense accelerations and decelerations, while large-sided games can elicit more high-speed displacements (277). Moreover, considering that football players cover short distances while sprinting (277), practitioners are encouraged to apply leading sprints, where players start at a rolling speed and achieve a maximal speed (278). The development of these capacities can prepare players for match opportunities and, at the same time, protect players by practicing efforts that could occur during matches, developing players' resilience to potential damaging efforts, such as high intensity decelerations (9).

Furthermore, the fact that U21 outperformed the other groups during field tests but not during matches, may be justifiable by players facing higher tactical constrictions. As so, coaches could prepare matches with the knowledge that few opportunities exist for players explore their maximal capacities. Additionally, considering a player peak speed, and maximal acceleration and deceleration during competition may help practitioners measure match load with real-scenario values.

Conclusions

In conclusion, our findings have showed that young football players differ at peak speeds, and maximum accelerations and decelerations. During field tests, maximum speed and acceleration performances increased with age, with U21 covering the specific distance in less time. However, during matches, U17 and U19 reached higher peak speeds, and higher acceleration and deceleration magnitudes. This data demonstrates that the expression of players' capacities during matches is context dependent, and U21 matches may inhibit players to reach their capacities. Coaches could adapt tactical strategies according to the age group characteristics, by expecting the occurrence or absence of higher peak speeds and higher maximal accelerations and decelerations. Future research could explore the contextual occurrences of maximal efforts.

Practical Applications

These findings represent an important information for coaches, which could better prepare their tactical approach to matches, by taking advantage of matches characteristics. According to our results, U17 and U19 matches facilitate players' expression of their speeds, accelerations, and decelerations maximum capacities, so coaches could train situations to explore those possibilities. However, developing players' capabilities is extremely important, even if matches limit players' expression of their maximal capabilities. Furthermore, the fact that U21 outperformed the other groups during field tests but not during matches, may be justifiable by players facing higher tactical constrictions. As so, coaches could prepare matches with the knowledge that few opportunities exist for players explore their maximal capacities. Additionally, considering a player peak speed, and maximal acceleration and deceleration during competition may help practitioners measure match load with real-scenario values.

4.9. Study IX (The path to sprinting: how soccer players sprint and what does the 25.2 km·h^{-1} threshold represent)

Citation: Silva H, Nakamura FY, Mendez-Villanueva A, Gómez-Diaz A, Menezes P, Marcelino, R. The path to sprinting: how soccer players sprint and what does the 25.2 km·h^{-1} threshold represent. (This scientific study is in submission process).

Abstract

This study investigated how soccer players reach efforts above the frequently used sprint threshold (> 25.2 km·h^{-1}) and what that fixed threshold represents to each player regarding their individual peak speeds registered during competition. Twenty professional players from a team competing in the Brazilian first division were monitored with a global position system during six matches. All efforts with final speeds > 25.2 km·h^{-1} were analyzed according to starting speed, the duration (ranging from 0.1 to 1.0 seconds) and the magnitude of the acceleration. Peak speeds for each player were also retrieved and compared to the sprint threshold. Most efforts > 25.2 km·h^{-1} (> 91%) start with very short accelerations (< 0.5s) and most (> 95%) start with high starting speeds (> 20 km·h^{-1}). Most accelerations that preceded efforts > 25.2 km·h^{-1} had magnitudes between 1-3 m·s^{-2} (53%). The 25.2 km·h^{-1} threshold represented an intensity of 71-91% of players' match peak speed. The inclusion of accelerations and peak speeds associated to the sprinting events that occur > 25.2 km·h^{-1} was shown to be useful for further characterization of football sprinting performance. In addition, the fixed threshold fails to individualize players' capabilities and performances, misleading load demands performed by players.

Keywords: football, leading sprint, match analysis, running, velocity

Introduction

During soccer matches, players need to cope with physical demands, and their "workload" is usually classified as External Training Load (58). This completed workload is then divided into variables such as accelerations and decelerations, total distance covered, average speed, and different running intensities or thresholds (255). By applying thresholds and intensities, practitioners and researchers intend to categorize efforts which can present high or less relevance for their context. For example, to account for high-intensity efforts, a filter is applied to exclude all efforts that fail to reach that intensity level. However, thresholds and intensities definitions are inconsistent in the literature, with different speed thresholds representing the same intensities' labels (19). For example, sprint threshold ranged from 19.8 $km \cdot h^{-1}$ and 30 $km \cdot h^{-1}$ (279). The reason why one or another threshold is used remains unexplained, especially if considering that running at a constant speed does not influence the metabolic cost (280).

These fixed thresholds present two major issues: intra-individual and inter-individual comparisons. First, if peak speed assessed during matches differ between playing positions and individual players (206,268), why would the same fixed threshold be suitable for all players? Second, players can change their capacities, altering distances covered at specific velocities thresholds (279). Although absolute velocities can show if a player can reach to the ball frit than the opposition, training and match load can be compromised. Additionally, Di Salvo et al. (281,282) separated sprints (> 25.2 $km \cdot h^{-1}$) as explosive – "attainment of sprint speed (> 25.2 $km \cdot h^{-1}$) from either standing, walking (< 7.2 $km \cdot h^{-1}$), jogging (< 14.4 $km \cdot h^{-1}$) or running (< $km \cdot h^{-1}$) with time spent in the high speed run category (from 19.8 to 25.2 $km \cdot h^{-1}$) less than 0.5 s – and leading – "defined as the attainment of sprint speed from either standing, walking, jogging or running whilst entering the high speed run category for a minimum of 0.5 s" – with players performing more efforts from the latter type. Another distinction in sprints divided efforts in short (< 5 seconds) and long (> 5 seconds) durations, with players performing more short sprints during matches (283). Therefore, while two efforts can have the same threshold (> 25.2 $km \cdot h^{-1}$), they can differ from each other regarding how they were achieved. Considering that players' acceleration capacity decreases as the starting speed increases (24), the acceleration that precedes a sprint would also influence the achieved speed.

This sprint type separation (explosive/leading and short/long) prompts a reflection of the importance of field tests to determine players' maximal speeds. That is, if leading sprints are more frequent during competition, assessing players during competition or training would probably be more advantageous than performing tests with standing starts

(284). Furthermore, previous research reported that players achieve lower peak speeds during matches and training sessions than during field tests (206).

Considering that match sprints were associated with muscle injuries (84) and are the most frequent powerful action before a goal (285), it would be important to understand how sprint efforts occur. Therefore, the aim of this study is to investigate how soccer players reach the sprint threshold (> 25.2 $km \cdot h^{-1}$) and what that fixed threshold represents to each player regarding their individual maximal capacities registered during competition.

Methods

Study design

Professional football players from one Brazilian team that competed in the 1st national division were monitored during 6 consecutive matches of the 2022 season. All analyzed matches were played within a month. We analyzed the velocities and accelerations from players to characterize efforts usually classified as sprints, using the most commonly used threshold: > 25.2 $km \cdot h^{-1}$ (279).

Subjects

Twenty male professional players (mean ± SD, age: 27.8 ± 5.3 years, height: 179.4 ± 5.9 cm and body mass: 73.3 ± 6.5 kg) were monitored during competition. Coaching staff divided players according to their playing position: central defenders (CD), fullbacks (FB), central midfielders (CM), wide midfielders (WM) and forwards (FW). Goalkeepers were excluded from this study due to the differences in their sprinting characteristics. Additionally, only players that completed full matches were selected. Number of players and match files are presented in Table 18. Ethics Committee clearance was obtained by the University Institute of Maia (35/2021) and the study was conducted in accordance with the Declaration of Helsinki. Written consent was obtained by the club.

Table 18. Sample characteristics as number of players, number (mean and range) of matches per playing position cited.

	CD	FB	CM	WM	FW
Players (n)	4	3	5	5	3
Matches (mean)	5.0	3.3	3.6	4.8	5.7
Match range (n)	4-6	1-5	1-6	4-6	5-6

Note: CD=central defender; FB=fullback; CM=central midfielder; WM=wide midfielder; FW=forward.

Procedures

The team monitored their players using a 10 Hz global positioning system (WIMU Pro – Realtrack Systems) that encompassed a double constellation system (GNSS and GPS). This device is FIFA certified (Certification number: 1004497) and the 10 Hz sampling rate has been validated for velocity measurements (45), (286). Additionally, this device presented a high degree of agreement (ICC>0.84) with an ultra-wide band (UWB) (287), and showed an intra-unit reliability ranging from 0.935 to 0.984 when assessing sprint displacements (linear, circular, and zigzag) (288). Devices were secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use, in accordance with the manufacturer's instructions, and each player used always the same individual device.

Competition raw data were retrieved from the GPS software (WIMU SPRO) as velocity ($m{\cdot}s^{-1}$) and time (milliseconds). Accelerations ($m{\cdot}s^{-2}$) were calculated with velocity and time (one acceleration consisted of the increase of velocity divided by the time passed during that increase – without establishing minimum effort duration (218)). The variables analyzed were time, initial velocity (starting speed), final velocity and acceleration. To avoid potential noise in data, accelerations above 9.5 $m{\cdot}s^{-2}$ and speeds above 44.45 $km{\cdot}h^{-1}$ were excluded (37,191). Additionally, since we collected raw data, small speed changes that could represent noise or insignificant displacements (i.e., velocity increases < 1 $km{\cdot}h^{-1}$) were not automatically excluded. As so, we only counted speed changes if there was a minimum speed difference > 1.0 $km{\cdot}h^{-1}$ (before and after the effort started). For example, if one player accelerated from 25 $km{\cdot}h^{-1}$ to 25.5 $km{\cdot}h^{-1}$, that effort would be excluded. All efforts with final speeds > 25.2 $km{\cdot}h^{-1}$ were selected. Efforts were analyzed with the starting speed (that could be lower, equal or higher than 25.2 $km{\cdot}h^{-}$

^{1}) that preceded the effort, and the time (0.1 to 1.0 seconds) and magnitude of the acceleration (m·s^{-2}) that led to a final speed > 25.2 km·h^{-1}. Starting speeds were grouped to a fixed bandwidth with a 5 km·h^{-1} interval (0-5 km·h^{-1}, 5-10 km·h^{-1}, 10-15 km·h^{-1}, 15-20 km·h^{-1}, 20-25 km·h^{-1}, >25 km·h^{-1}), and accelerations were grouped to a fixed bandwidth with 1 m·s^{-2} intervals (0.01-1 m·s^{-2}, 1-2 m·s^{-2}, 2-3 m·s^{-2}, 3-4 m·s^{-2}, 4-5 m·s^{-2}, >5 m·s^{-2}). Finally, match peak speed was calculated as the highest speed registered, with one pre-requisite: one additional effort with speed no smaller than 1 km·h^{-1} from the higher speed (for example, if one player achieved 32.7 km·h^{-1} as peak speed, another effort no smaller than 31.7 km·h^{-1} was required). With this filter we ensure that match peak speed was indeed achieved and not a potential error not filtered (due to using raw data). With individual peak match speeds, a relative intensity was calculated according to the absolute threshold (25.2 km·h^{-1}): what percentage of peak match speed would the absolute threshold represent for each player.

Statistical analysis

Descriptive statistics were conducted for percentage of occurrences for each duration interval (0.1 seconds to 1.0 seconds), for each starting speed bandwidth (0-5 km·h^{-1}, 5-10 km·h^{-1}, 10-15 km·h^{-1}, 15-20 km·h^{-1}, 20-25 km·h^{-1}, >25 km·h^{-1}), and for each acceleration bandwidth (0.01-1 m·s^{-2}, 1-2 m·s^{-2}, 2-3 m·s^{-2}, 3-4 m·s^{-2}, 4-5 m·s^{-2}, >5 m·s^{-2}). Match peak speeds were analyzed individually and for each playing position (mean ± SD).

Differences between peak speeds of the different playing positions were estimated with independent groups contrasts, with 95% CI, in jamovi with ESCI package (192,193). If the 95% CI crossed zero, differences were considered unclear.

Results

Final speeds ranged from 25.21 km·h^{-1} to 35.72 km·h^{-1}. Most efforts that reached speeds > 25.2 km·h^{-1} started with very short accelerations, with durations equal or inferior to 0.5 seconds (> 91% of all efforts) (Figure 27). Most of those efforts had accelerations with magnitudes of 1-4 m·s^{-2} (> 75%) and initial velocities > 20 km·h^{-1} (> 95%) (Figure 28).

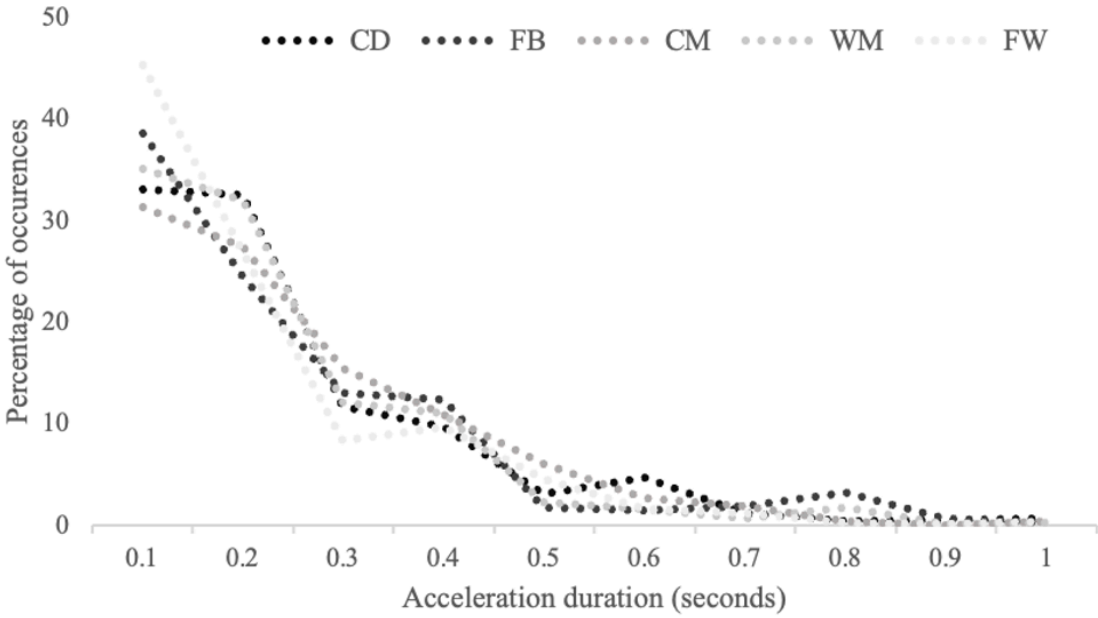

Figure 28. Percentage of efforts per duration of the acceleration that finished above 25.2 km·h^{-1}. CD=central defender; FB=fullback; CM=central midfielder; WM=wide midfielder; FW=forward.

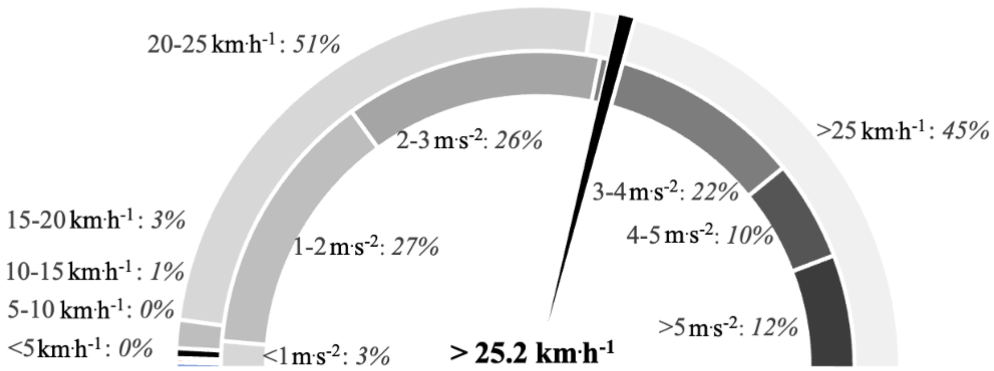

Figure 29. Distribution (as percentage of efforts) of accelerations intensities (inner semi-circle) and starting speeds (external semi-circle) that preceded efforts that ended > 25.2 km·h^{-1}.

The 25.2 km·h^{-1} represented an intensity of 71-91% of their peak speed and, for FB and FW, the fixed threshold represented a relative lower demand than for other positions (78.9% and 75.2%, respectively) (Figure 29). No clear differences were found between positions in peak speeds achieved during matches (CD vs FB: 0.50 [-3.36, 4.36]; CD vs CM: 0.34 [-3,05, 3,73]; CD vs WM: 1.78 [-1.61, 5.17]; CD vs FW: 0.96 [-2.90, 4.82]; FB vs CM: -0.16 [-3.85, 3.53]; FB vs WM: 1.28 [-2.41, 4.97]; FB vs FW: 0.46 [-3.67, 4.59]; CM vs WM: 1.44 [-1.76, 4.64]; CM vs FW: 0.62 [-3.07, 4.31]; WM vs FW: -0.82 [-4.51, 2.87]).

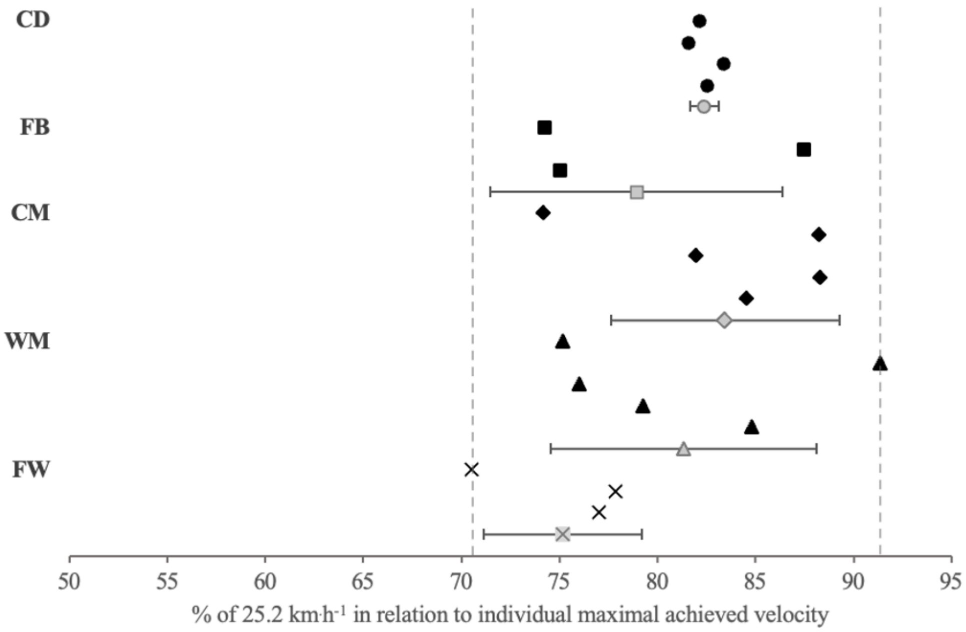

Figure 30. Individual and mean (± SD) percentage of effort per playing position: what the 25.2 km·h^{-1} threshold represents as an % of the individual match peak speed. Note: Black symbols represent the individual effort of each player, and grey symbols represent the mean ± SD. CD=central defender (dots); FB=fullback (squares); CM=central midfielder (diamonds); WM=wide midfielder (triangles); FW=forward (crosses).

Discussion

With this study, we aimed to understand how soccer players reached efforts above the most commonly used absolute sprint threshold (> 25.2 km·h^{-1}) and what that threshold represents considering players' peak speeds registered during competition. The main findings of this study were that most efforts ending > 25.2 km·h^{-1} resulted from short accelerations (< 0.5 seconds) that generally started at high speeds (> 20 km·h^{-1}); and the absolute threshold would represent a relative intensity ranging from 71 to 91%.

Regarding the duration of the effort (i.e., sprints), our results indicate that sprints are preceded by very short accelerations which means that if the traditional minimum effort duration filter (0.5 seconds) is applied (an effort to be counted must be maintained for a minimum of 0.5 seconds), these accelerations could be excluded (13). This is an important finding, as speed changes elicit higher metabolic demands than running at a constant speed (280). Our findings also support the idea that leading sprints are more frequent during matches than explosive sprints (281), because sprints appear to occur mainly with short accelerations (Figure 27).

To achieve the sprint threshold in a very short time window, at least one of two options must occur: the acceleration needs to have a high magnitude, and/or the effort must start from a high speed. According to our results, the second option appears to be the most prevalent, as most accelerations' magnitudes ranged between 1-4 $m{\cdot}s^{-2}$ (Figure 28). Accelerations between 1-4 $m{\cdot}s^{-2}$ differ in their classification: from low to maximal-intensity efforts (194). However, it is important to highlight that as the starting speed increases, the acceleration capacity decreases (24), which means that the different magnitudes can impact players differently. Nevertheless, it was clear that players mostly perform accelerations from high starting speeds towards a sprint or peak speed, while standing starts or low speed starts (< 5 $km{\cdot}h^{-1}$) were practically inexistent (~ 0.5%). With this, we can question if field tests should be adapted to assess players maximal capabilities in relation to performance, as sprints that started from standing positions appear to be practically inexistent during matches. Providing a leading start could, therefore, provide a more match-related situation. Furthermore, players would probably benefit more from training sprints with high starting speeds as sprints appear to occur from high initial speeds, making it difficult to perform high absolute magnitude accelerations (24).

By assessing players with maximal speed tests, practitioners evaluate the maximal speed that a player can achieve from a static start which differs from what happens during matches. Different studies report that players fail to replicate their maximal test speed during matches, where players achieve around 90% of their maximal tested speed (205,206,275,284). In this study, we retrieved the maximal value obtained for each player during all analyzed matches and placed the fixed sprint threshold (> 25.2 $km{\cdot}h^{-1}$) to gain insight into what that threshold would represent to each player. This confirms a piece of important information: the fixed threshold represents a different relative intensity to each player (19). Therefore, using it fails to correctly assess individual match demands. For instance, for one player, the threshold represented 91% of their match peak speed, while for other that threshold represented 71% (Figure 29). As so, if one reported the number of efforts or the distance covered > 25.2 $km{\cdot}h^{-1}$ for these two players, the first player would probably perform less efforts or cover less distance because that threshold is much closer to his maximum. Additionally. This would also impact training monitoring, as match peak speed surpassed the peak speed registered during different sided games formats (4vs.4 + 2, and 8vs.8 + 1) (289).

This fixed sprint threshold (> 25.2 $km{\cdot}h^{-1}$) was first used – to the best of our knowledge – by Rampini et al. (290) in 2007, supplied by the video-computerized match analysis system. (27). Considering that matches have been developing to a faster game, with higher distances sprinting (291,292), maintaining the same threshold could not be the best strategy to monitor match demands. As so, using a relative and individual threshold would account for both players individual capacity and matches evolutions. Additionally, differences between playing positions have been previously reported (293), but using fixed thresholds could change the retrieved data. In our study, the absolute sprint threshold represented a lower demand to FW (75.2%) and FB (78.9%) than for CM (83.5%), CD (82.4%) and WM (81.3%). This means that FW could cover higher sprint distances (> 25.2 $km{\cdot}h^{-1}$) than CM just because it would represent a lower demand for FW.

Importantly, we used peak match speeds as the highest reference speed, which was retrieved from a small sample size (6 matches). Nevertheless, since players do not reach their field test maximum speed during matches, using a larger sample could potentially provide a more reliable peak speed, while considering the real scenario. Additionally, considering that tactics influence the registered sprint distance (294), analyzing different teams can strengthen those analysis. Furthermore, our purpose was to analyze what happened before a player reached a speed > 25.2 $km{\cdot}h^{-1}$ and not for how long he could maintain a speed > 25.2 $km{\cdot}h^{-1}$. As so, analyzing differences between distances covered with relative and absolute thresholds could highlight the need for an individualized sprint threshold. The suggested sprint relative threshold of > 80% (181) could be a good starting point, and within the individual range of the absolute threshold (71-91%) reported in this study.

Conclusions

Our study showed that sprint efforts were achieved with short accelerations and started with high speeds. By defining sprints as efforts occurred > 25.2 $km{\cdot}h^{-1}$ for a specific minimum effort duration, practitioners potentially exclude high-intensity accelerations, especially if the effort starting speed is considered. The fixed threshold also fails to individualize players' capabilities and performances, misleading load demands performed by players. With this, practitioners should consider testing sprint capacities by providing a leading start instead of a standing start, since sprints that start from stationary positions are practically inexistent during matches. Furthermore, since the absolute threshold can represent different intensities for different players (and positions), sprints during matches should be monitored with relative and individualize thresholds.

Practical Applications

Practitioners could benefit from using relative intensities when analyzing efforts, because the fixed threshold represent different intensities for different players. Considering that players do not achieve field tests peak speeds during matches, establishing maximal values from fields tests performance could potentially show a misleading load, with players covering shorter distances at a specific intensity. Instead, peak speeds registered during matches could provide a more realistic picture regarding demands intensities.

Additionally, efforts should be counted as they are - that is, if one player is accelerating, that should be classified as an acceleration. For example, considering time spent > 25.2 $km \cdot h^{-1}$ solely as sprints could potentially ignore intense accelerations or decelerations from the real players' load. Considering that these short efforts intensities may differ according to starting speed, it is crucial to consider accelerations and decelerations that occur at sprint speeds, even if they represent a lower absolute threshold.

4.10. Study X (Peak match sprinting speed during soccer matches: analyzing the pre- and post- peak speed dynamics)

Citation: Silva H, Nakamura FY, Racil G, Gómez-Diaz A, Menezes P, Chamari K, Marcelino, R. Peak match sprinting speed during soccer matches: analyzing the pre- and post- peak speed dynamics (This study is currently under review by a scientific journal)

Abstract

This study aimed to characterize match peak speeds, during a 20-second time window (10 seconds immediately before and after the match peak speed), in soccer matches. Twenty elite soccer players were monitored with GNSS devices during six soccer matches from the Brazilian first division. For each player during each match, speeds were collected at 0.1-second intervals (10 Hz) from 10 seconds before and 10 seconds after the match peak speed. Speeds (mean ± SD) were calculated for speeds at each 0.1-second intervals and intra-individual speed differences were compared at every second of the 20 seconds window using paired mean differences. Effect sizes (ES) were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals. Match peak speeds ranged from 29.11 km/h to 31.64 km/h. Speeds registered 10 seconds before and 10 seconds after the match peak speed ranged from 5.11 km/h to 9.21 km/h and 6.90 km/h to 7.65 km/h respectively. Speed increased (acceleration) moderately (ES: 0.68 [0.64, 0.72] 4 seconds before the match peak speed and decreased (deceleration) moderately (ES: -0.73 [-0.77, -0.69]) 3 seconds after the maximal effort. Match peak speeds were achieved from leading starts, which questions the current sprint tests procedures. After the match peak speed, players decelerate quicker than they accelerated but without reaching a full stop. Nevertheless, preparing players for intense decelerations should not be disregard. Field tests and training sessions should provide similar stimulus from what is observed during competition.

Keywords: acceleration, deceleration, football, match analysis, running

Introduction

Soccer players are often tested to assess individual strengths and weaknesses and to evaluate the effectiveness of training programs (295). Sprint test is one of these tests and is used to assess players capacity to quickly accelerate and achieve/maintain a maximal speed in 10-30 m distances (296). With tests results, practitioners identify the faster players and the ones who need to develop their speeds capacities, taking into consideration their playing role and individual characteristics. However, peak speeds achieved during tests generally exceeds matches peak speeds (206,297). The differences observed can probably be explained by the starting conditions of the sprint, since 84% of the achieved peak speed is obtained in the first 10 of the 30 m standard sprint test (298). Considering that match sprints are usually shorter than 10 m (282), a standing start would probably not allow them to reach their peak speed. Moreover, match situations, such as counter attacks, need to occur to allow players to reach maximal speeds. For instance, forwards (FW) could have more space to run as they usually face only the defense line, while center midfielders (CM) could suffer more pressure and have less space to develop high-speed actions (299).

Di Salvo and colleagues (282) classified sprints into two types: "explosive" and "leading." They found that there were more "leading" sprints during matches. "Explosive" sprints were defined as those where players reached the sprint threshold (> 25.2 km/h) without entering the high-speed running category (19.8-25.2 km/h) in the previous 0.5 seconds. On the other hand, "leading" sprints were defined as those where players achieved the sprint threshold while entering the high-speed running category in the previous 0.5 seconds. This means that players accelerate gradually to reach sprint threshold rather than performing fast accelerations. Additionally, players performed more “short” (<5 seconds) than “long” (> 5 seconds) sprints during matches (283). Therefore, during competition, sprint speeds (> 25.2 km/h) are achieved gradually but maintained for a short period of time (< 5 seconds).

However, this analysis has been focusing on the sprint threshold, while little is known on how players achieve match peak speeds. For instance, considering the sprint test characteristics, one may question the validity of standing starts, as testing procedure, since sprint performances are significantly influenced by the leading distance (distance before the initial timing gates) (300). Ideally, field tests should provide similar context to competition, increasing the retrieved data utility.

By understanding how players achieved their match peak speed, practitioners can develop training strategies or test procedures to improve and assess sprint ability in soccer players. Furthermore, game success can even increase, as sprints are closely related to goal situations (285). Additionally, even if sprints increase the risk of hamstring injuries, the progressive exposure of players to these intense efforts can provide an important protective effect (301). Therefore, the purpose of this study is to characterize match peak speeds, by analyzing how players reach and leave those efforts, during a 20 second time window (10 seconds immediately before and after the match peak speed).

Methods

Experimental Approach to the Problem

During the 2022 season, a cohort of professional soccer players from a highly ranked Brazilian team was subjected to monitoring over the course of six consecutive national first division matches. Subsequent to the acquisition of raw data from the players, a comprehensive analysis was performed in order to establish match peak speeds.

Subjects

This study included twenty male elite players with an average age of 27.8 ± 5.3 years, height of 179.4 ± 5.9 cm and body mass of 73.3 ± 6.5 kg. These players were monitored during competition and were divided (by coaching staff) into playing position: 4 central defenders (CD), 3 fullbacks (FB), 5 central midfielders (CM), 5 wide midfielders (WM) and 3 forwards (FW). The number of matches played by each player ranged from 3 and 6. Goalkeepers were excluded from this study. Data collection occurred as part of the club’s standard procedure for monitoring match load, and therefore did not require approval from an Ethics Committee (48). Nevertheless, players were aware of the general research objectives and provide their consent.

Procedures

Players were monitored a 10 Hz global positioning system (WIMU Pro – Realtrack Systems) that encompassed a double constellation system (GNSS and GPS) as standard procedure. This device was certified by FIFA (Certification number: 1004497) and previously validated (45). Devices were secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use, in accordance with the manufacturer's instructions. To avoid interunit error, each player used the same WIMU device throughout the data collection time period.

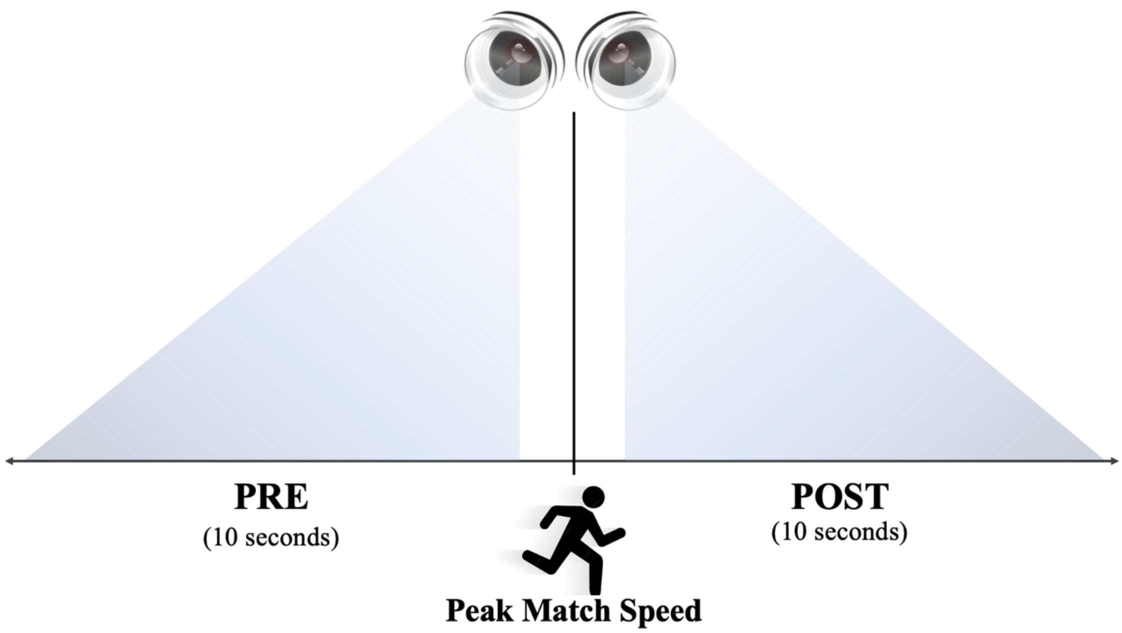

Figure 31. Illustration of the approach to analyze the pre and post dynamics of the peak match speed.

Competition raw data were retrieved from the GPS software (WIMU SPRO) as speed (km/h) and time (milliseconds). By analyzing raw data, which was not treated by the equipment software, filters were created to minimize potential noise: first, speeds above 44.45 km/h were excluded (37); second, the players' highest speed achieved during each match was recorded as the match peak speed, provided that another effort within 1 km/h slower than the peak speed occurred during the same match (e.g., 32.7 km/h would be a valid peak speed if another effort was registered at a speed ≥ 31.7 km/h), and if the match peak speed was superior to the sprint threshold (> 25.2 km/h). For each player during each match, speeds were collected at 0.1-second intervals (10 Hz) from 10 seconds before and 10 seconds after the match peak speed (Figure 30).

Statistical analysis

Mean ± SD were calculated for speeds at each 0.1-second interval, according to the playing position and for all the players. Speed differences during selected timeline were compared at every second of the 20 seconds window using paired mean differences, which were estimated in jamovi with the ESCI package (192,193). An intraindividual comparison was performed by comparing the individual speeds registered at one second intervals (consecutive intervals). These differences were calculated for each second within the timeline (9-10 seconds before, 8-9 seconds before, and so on, until 9-10 seconds after the maximal effort). This procedure was repeated for each player match peak speed. Cohen's *d* effect sizes were established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% confidence intervals (54). If the confidence interval crossed zero, the effect size was considered unclear (55). Match peak speeds differences between playing positions were analyzed using independent mean differences, which were estimated using the jamovi with the ESCI package (192,193). Cohen's *d* effect sizes were calculated and categorized in the same way as described above.

Results

Match peak speeds ranged from 29.11 km/h to 31.64 km/h, and speeds registered 10 seconds before and 10 seconds after the registered peak speed ranged from 5.11 km/h to 9.21 km/h and 6.90 km/h to 7.65 km/h respectively (Table 19).

Table 19. Mean ± SD speeds (km/h) for each 1 second interval and for peak speeds registered according to playing positions (n=number of match peak speeds).

Timeline (seconds)	CD *n*=20	FB *n*=10	CM *n*=19	WM *n*=24	FW *n*=17
-10	5.11±3.60	7.40±4.09	8.02±4.94	8.30±5.43	9.21±6.84
-9	5.53±4.34	8.78±6.02	8.54±4.89	8.42±6.87	7.96±5.34
-8	7.07±5.08	10.03±7.58	9.37±4.71	9.18±6.94	8.88±5.39
-7	8.18±5.10	11.24±7.65	10.39±5.15	9.47±6.19	8.99±5.18
-6	9.35±5.95	13.08±8.57	12.59±5.12	10.05±6.30	8.78±5.10
-5	11.99±5.69	15.07±9.04	16.69±4.70	12.28±6.66	9.45±5.55
-4	14.59±7.21	18.93±7.86	18.49±5.10	16.40±6.45	12.70±5.83
-3	18.02±6.54	22.53±5.32	21.20±5.19	21.48±4.97	18.85±4.59
-2	22.48±5.50	26.57±3.80	24.54±4.08	25.43±3.27	24.03±2.74

-1	25.75±5.08	29.29±3.15	27.43±2.95	28.67±2.46	27.38±2.39
Match Peak Speed	*29.11±1.64*	*31.64±1.94*	*30.26±2.23*	*30.68±2.61*	*29.83±1.88*
+1	25.34±5.61	27.83±4.97	27.68±3.08	26.82±5.47	26.72±3.62
+2	20.14±6.55	20.85±8.14	21.97±6.63	19.12±8.91	20.02±7.14
+3	14.91±7.63	13.74±7.92	15.05±7.54	13.23±9.56	14.78±6.78
+4	12.55±7.19	11.56±6.55	12.27±6.72	10.46±8.94	10.77±5.21
+5	11.07±6.11	11.37±5.72	9.80±6.00	10.13±8.20	9.39±5.22
+6	8.74±5.84	10.66±4.26	9.51±5.11	9.91±6.60	8.74±5.13
+7	7.63±5.50	8.83±5.40	9.15±4.60	9.40±5.66	8.28±4.48
+8	7.59±5.41	7.92±5.69	7.88±4.24	8.39±5.38	7.71±3.56
+9	7.47±5.09	7.65±6.19	6.90±4.11	7.46±5.75	7.41±3.61
+10	7.34±4.62	7.45±6.31	6.58±4.23	7.01±5.11	6.55±3.01

Note: CD=Central defenders; FB=Fullbacks; CM=Central midfielders; WM=Wide midfielders; FW=Forwards.

Across the collect data, higher speeds variations were registered further to the match peak speed as seen by the SD represented in Figure 1. Players ranged between 5 and 10 km/h during the first and last 5 seconds of the monitored time window (10 to 5 seconds before the match peak speed and 5 to 10 seconds after the match peak speed) (Figure 31).

Speed increased (acceleration) moderately 4 seconds before the match peak speed and decreased (deceleration) moderately 3 seconds after the maximal effort (Table 20), highlighting that players decrease their speed faster than how they increase their speed. Additionally, speed changes (accelerations and decelerations) were higher (> 1 km/h) immediately before and after the match peak speed (Figure 32).

CD had lower match peak speeds than FB (Effect Size ± 90% CI; ES: 1.40 [0.75, 2.22]), CM (ES: 0.57 [0.04, 1.14]) and WM (ES: 0.92 [0.27, 1.70]), and FW reached lower match peak speeds than FB (ES: 0.92 [0.27, 1.70]). Remaining differences between playing positions were unclear.

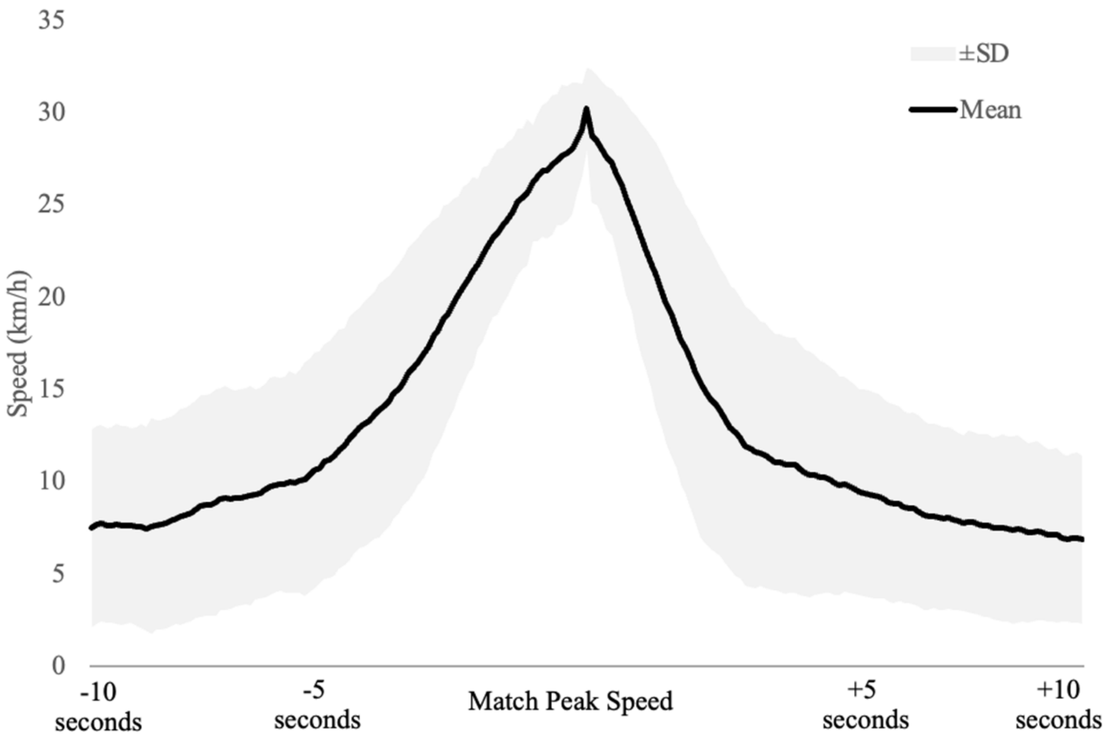

Figure 32. Individual registered speeds (km/h) during the 20 second window (10 seconds before and 10 seconds after the match peak speed). Speed variance decreases (smaller SD) near the match peak speed.

Table 20. Effect sizes (90% Confidence Interval) in mean paired differences, of speed differences between 1 second consecutive intervals.

Timeline (seconds)	Effect Size (90% CI)	
10-9	0.03 (-0.01, 0.07)	*Unclear*
9-8	0.18 (0.15, 0.21)	*Trivial*
8-7	0.12 (0.08, 0.15)	*Trivial*
7-6	0.17 (0.13, 0.21)	*Trivial*
6-5	0.37 (0.33, 0.41)	*Small*
5-4	0.46 (0.42, 0.50)	*Small*
4-3	0.68 (0.64, 0.72)	*Moderate*
3-2	0.84 (0.80, 0.88)	*Moderate*
2-1	0.80 (0.77, 0.84)	*Moderate*
Match Peak Speed		
1-2	-1.04 (-1.09, -0.99)	*Moderate*
2-3	-0.73 (-0.77, -0.69)	*Moderate*
3-4	-0.38 (-0.42, -0.35)	*Small*
4-5	-0.15 (-0.18, -0.12)	*Trivial*
5-6	-0.16 (-0.18, -0.13)	*Trivial*

6-7	-0.18 (-0.21, -0.15)	*Trivial*
7-8	-0.13 (-0.16, -0.10)	*Trivial*
8-9	-0.09 (-0.11, -0.06)	*Trivial*
9-10	-0.08 (-0.10, -0.05)	*Trivial*

Discussion

The aim of this study was to analyze what happens in terms of speed variation before and after a player reaches individual peak match speeds. This is an important topic, where information is still scarce: if peak speeds are mainly reached during lead sprints, instead of explosive sprints, training drills and fields tests should be adapted accordingly, providing similar conditions. The main findings of this study were that match peak speeds are generally reached with progressive speed increases and not with explosive accelerations, and without standing start positions. This novelty findings question the validity of how sprint field tests are applied, which failed to mimic what happens during competition. Additionally, after reaching their match peak speeds, players decelerate faster than they accelerated, but without complete stops. This is also an important finding, which shows that players protect themselves from very intense decelerations.

Since matches elicit short and intense efforts from players, reaching speeds higher than those obtained in > 20 m sprinting tests would be difficult (274,275). In our study, we assessed match peak speeds achieved during six competitive matches, which represent players' maximal values for competition and not their absolute maximal values, as maximal speeds registered during matches are usually equivalate to 90% of players' maximal speeds registered during field tests (205,206,275,284). This means that field tests probably fail to mimic the sprints taking place in real competitive scenarios. In our study, mean peak speeds ranged from 29.11 km/h (CD) to 31.64 km/h (FB), with wide positions reaching higher values, while previous research reported higher values for FW during matches (206,265,284). These differences could be explained by the match variability since sprint actions occur within different phases of the match and during different tactical outcomes (302).

Regarding field tests, we also questioned the applicability of static starts that did not occurred in our study, even looking back for 10 seconds. Interestingly, most speed differences (at each 0.1 seconds intervals) occurred within 3 seconds before and after the match peak speed (Table 19). As so, to replicate competition, sprint field tests should start with players running (probably > 10 km/h) and accelerating for no more than 5 seconds. One strategy could be increasing the distance behind the initial timing gate, which can lead to sprint times improvements (300).

Considering that soccer players reach their match peak speed from running starts, it is important to highlight that the ability to accelerate decreases when starting from high speeds (24), so magnitudes of accelerations that precede maximal speeds should be relatively low. We did not assess accelerations and decelerations magnitudes, but speed changes were higher near the match peak speed, which could mean that players probably fluctuate in their speed until 5 seconds prior to their match peak speed, where players increase their speed (Figure 21).

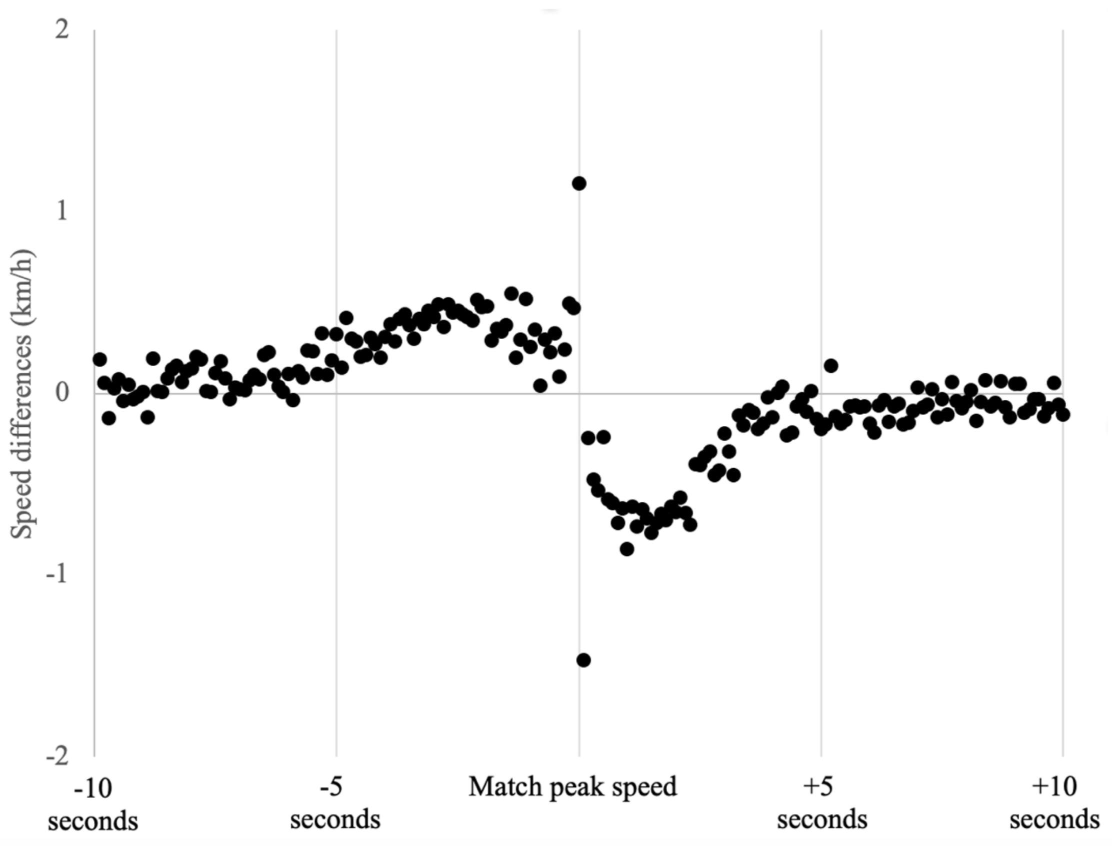

Figure 33. Speed changes for every 0.1 second within the 20 seconds timeline (10 seconds before and after the match peak speed). Speed changes near 0 km/h probably represent speed fluctuations, which occurred mainly between 10 to 5 seconds prior and 5 to 10 seconds after the match peak speed. Speed changes above 1 km/h occurred only immediately before (acceleration) and after (deceleration) the match peak speed.

After achieving their match peak speeds, players decelerated quicker than they accelerated, except for CD (Figure 31). This comes with no surprise as it is easier to perform explosive decelerations from high speeds than to perform explosive accelerations. However, players do not reach full stop, returning their velocity to 5-10 km/h. As so, the same match situation that allowed players to reach their match peak speeds, also allowed players to progressively decrease their speed. This is an important consideration, as intense decelerations expose players to higher hamstring and knee (anterior-cruciate ligament) injury risk (20).

We found higher speed changes within 3 seconds of the match peak speed (Table 19), and, during this period, players increased (before) and decrease (after) their speed by ~ 10 km/h and ~ 16 km/h respectively (Table 18). This probably means that a particular match situation elicited a reaction from players around 3 seconds before they reached their match peak speed. Similarly, since no sudden stop was reported (on average) following match peak speeds, players were probably not required to perform a sudden, angle closed, change of direction (303). However, future studies should synchronize GPS data with video to describe properly the contexts in which soccer players reach match peak speeds, and how (and why) they decelerate.

Our study is limited by the lack of other contextual factors analysis. For example, match location (home or away) and outcome (win, draw or loss) affect physical demands registered in soccer players (196), and we have not included these situations in our study. Nevertheless, this study highlights the past and the future (pre and post) of match peak speeds, to a large timeline period (10 seconds), which can create new perspectives for future studies involving different and larger cohorts.

Considering our findings, assessing players with field tests and particularly with static starts does not recreate the competitive scenario. As so, practitioners should use field tests only to assess players condition after a period of competition/training absence (off-season or after an injury); or they should adapt their test, allowing players to start sprints with leading speeds, and allowing short times to achieve their maximal speeds. More importantly, sprint training designed for soccer players should incorporate such efforts (i.e., leading instead of explosive sprints). For example, previous research identified vertical-oriented plyometrics as better appropriate than while horizontal-oriented plyometrics to develop accelerations between 10-20 m (304). According to our findings, the ability to accelerate from leading starts may represent higher importance to reach match peak speeds than the ability to accelerate from static starts, which is in line with previous research that suggested flying sprints to develop maximal speeds (278).

Furthermore, even if soccer players progressively decelerate from match peak speeds, practitioners should prepare players for high-intensity decelerations, due to the potential injury risk associated with those efforts (20).

Conclusions

In conclusion, our study presents a novelty approach regarding match peak speed, analyzing those efforts during a prolonged time window (20 seconds). This analysis allowed us to registered speed changes occurred 10 seconds before and 10 seconds after the match peak speed of different soccer players. We found that match peak speeds were achieved from leading speeds, instead of standing starts, which questions the current sprint tests procedures. Additionally, since players reach higher accelerations 3 seconds before the match peak speed, field tests should provide flying starts and short time periods for players to reach their peak effort. After the match peak speed, players decelerate quicker than they accelerated but without reaching a full stop. Although being an encouraging finding – with players avoiding very intense decelerations – practitioners should continue to prepare players to perform intense decelerations, especially considering the risks involve with those actions. Finally, how players reach match peak speeds during matches should be replicated during training sessions, which can be achieved with sprint training with flying starts. Finally, while monitoring peak efforts, practitioners should also consider playing positions as differences may be expected. These differences may occur due to individual capacities or due to match context. While wide positions may have more field space to achieve peak speeds, players capacities should be developed to ensure that players would be ready to decisive match moments.

Practical Applications

Assessing players with field tests and particularly with static starts does not recreate the competitive scenario. As so, practitioners should use field tests only to assess players condition after a period of competition/training absence (off-season or after an injury); or they should adapt their test, allowing players to start sprints with leading speeds, and allowing short times to achieve their maximal speeds. More importantly, sprint training designed for soccer players should incorporate such efforts (i.e., leading instead of explosive sprints). Furthermore, even if soccer players progressively decelerate from match peak speeds, practitioners should prepare players for high-intensity decelerations, due to the potential injury risk associated with those efforts.

4.11. Study XI (Does the pro-agility test and training sessions mimic soccer matches peak accelerations and decelerations?

Citation: Silva H, Nakamura FY, Roriz P, Marcelino, R. Does the pro-agility test and training sessions mimic soccer matches peak accelerations and decelerations? (This study is currently under review by a scientific journal)

Abstract

Change of direction speed tests can provide insights about the acceleration and deceleration abilities of soccer players. We compared peak accelerations and decelerations during matches, training sessions and the pro-agility test. Seventeen (n = 17) players from the men's Portuguese first division were monitored with global positioning system equipment during half of the season. Peak efforts were retrieved during matches, training sessions and the test. Mean paired differences and magnitude of effect were compared between matches, training sessions and the pro-agility test. Peak acceleration in the pro-agility test (4.64 ± 0.24 $m{\cdot}s^{-2}$) was similar to the peak accelerations performed match play (4.68 ± 1.09 $m{\cdot}s^{-2}$) (ES: 0.05 [90% CI: -0.58, 0.69]), but differ to training (4.94 ± 0.23 $m{\cdot}s^{-2}$) (ES: 1.22 [90% CI: 0.83, 1.72]). Peak decelerations differed between the pro-agility test (4.71 ± 0.35 $m{\cdot}s^{-2}$) and matches (6.04 ± 1.31 $m{\cdot}s^{-2}$) (ES: 1.35 [90% CI: 0.77, 2.07]) and training (6.62 ± 0.39 $m{\cdot}s^{-2}$) (ES: 5.02 [90% CI: 4.03, 6.48]). Finally, differences between matches and training sessions were unclear (ES: 0.31 [90% CI: -0.23, 0.89]) and small (ES: 0.59 [90% CI: 0.02, 1.21]) for peak accelerations and decelerations, respectively. Results of this study indicate while the magnitude of acceleration and deceleration in matches and training sessions are similar the pro-agility assessment only replicated the acceleration requirement and was not representative of the peak decelerations performed by players in matches and training sessions.

Keywords: agility, competition, performance, quickness, speed

Introduction

During soccer matches, players are constantly (every 4 to 6 seconds) alternating their activities (1), which elicits accelerations and decelerations (> 1 $m \cdot s^{-2}$) for almost 20% of the total match time (2). Additionally, players perform more than 700 changes of direction (COD) (2), contributing to neuromuscular fatigue lasting up to 72h (38). During soccer matches, players need to cope with different stimulus such as quickly react to opponents, the ball, and movements from teammates, which can elicit unanticipated movements described as agility (305). Whereas physiological tests for player performance typically involve a change of direction speed (CODS) (305) which is pre-planned. Contrarily, during matches, players need to be agile, by quickly reacting to different stimulus (306), which are frequently unpredictable in competition. Additionally, the unpredictable stimulus that occur during matches, increase the movement complexity, eliciting higher joint loads from players (20,307).

Different field tests have been used to assess CODS in team sports players, with different formats and cutting angles (43,308). For example, the number of COD can vary from 1, 2 or 4 according to the specific tests (5-0-5, pro-agility [5-10-5] and t-test, respectively) (43). Additionally, some tests start with players already running (leading start) (5-0-5) while others require a standing start (explosive start) (pro-agility). Finally, the cutting angle provides an important information to practitioners, with tests varying from 90º (t-test) to 180º (pro-agility) (43). Usually, practitioners choose the test with most similarities with the specific sport. Considering that most COD taking place during soccer matches have cutting angles inferior to 90º (2), one may conclude that tests with small cutting angles are the most suitable to this sport. However, players also perform a high number (around 100) of 90-180º turns per match (39), and higher cutting angles expose players at higher braking forces because players need to reduce their speed to zero before changing direction (10). Hence, during COD with high cutting angles, players need to perform high-intensity decelerations – to brake – and accelerations – to quickly return to a high speed.

Moreover, to the best of our knowledge, no study has compared peak accelerations and decelerations occurring during competition and during high cutting angles (180º) tasks (i.e., pro-agility test test). This will provide important information to practitioners by showing if CODS tests can correctly portrait the peak acceleration and deceleration demands that occur during matches, providing a more realistic perspective of CODS tests validation, by showing if players are ready to meet competition demands. Additionally, training sessions can provide an important protective effect to the musculoskeletal system, especially during decelerations efforts (8). As so, it would be interesting to explore whether training sessions portrait peak efforts during matches as CODS tests. Since the pro-agility test – a CODS test – has been proposed as a tool to provide information regarding acceleration and deceleration, in addition to 180º COD capabilities in sports, such as soccer (309), we aimed to compare peak accelerations and decelerations occurred during this CODS test, during matches and training sessions.

Methods

Experimental Approach to the Problem

During pre-season, players' maximal accelerations and decelerations were assessed using the pro-agility test, collecting peak accelerations and decelerations with GNSS devices. In the first part of in-season (immediately after pre-season), players' maximal accelerations and decelerations were assessed during the first 17 microcycles (including 17 competitive matches from the Portuguese first division: Liga Bwin; and 85 training sessions), collecting peak accelerations and decelerations with the same devices used during the pro-agility test.

Subjects

Seventeen (n = 17) men's national level players competing in the Portuguese first division participated in this study. Only players that performed the test and participated of 50% of matches were selected. Players' average age, height and body mass was 27.5 ± 5.2 years, 178.4 ± 7.1 cm, and 74.3 ± 7.3 kg. Playing positions include central defenders (*n*=3), fullbacks (*n*=5), central midfielders (*n*=7), wide midfielder (*n*=1) and forward (*n*=1). Ethics Committee clearance was obtained by the University Institute of Maia (35/2021) and the study was conducted in accordance with the Declaration of Helsinki.

Pro-agility test (5-10-5)

The pro-agility test was performed during the preseason period, on grass, with players wearing soccer boots as they usually wear during training and competition. After warm-up and test familiarization, players performed 2 attempts each of the test, with a minimum rest of 5 minutes between trials. Players placed themselves at the starting line, in upright position. After a whistle, players quickly accelerated to the left for 5 meters, changed direction to the right and ran for 10 meters, changed direction again to the left and ran for 5 meters to the finish line (Figure 3). Overall, players covered 20 meters, with two 180º changes of directions. Players were instructed and motivated to perform the test at their maximal capacity. While performing the test, players wore the same GNSS devices used during training sessions and matches.

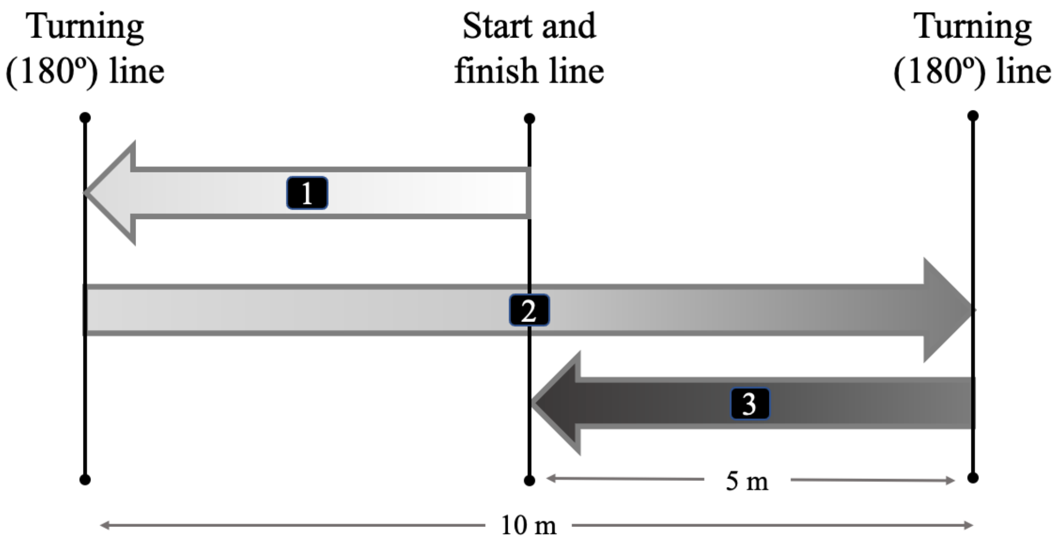

Figure 34. Pro-agility (5-10-5) test

Peak accelerations and decelerations assessment

Performances during the pro-agility test, matches and training were assessed with players using a 10 Hz global positioning system (Catapult Vector S7 – Catapult Sports, Melbourne, Australia) that included a double constellation system (GNSS and GPS). This model is FIFA certified (190). Devices were secured between the upper scapulae, at approximately the T3-4 junction and were activated 15 minutes before use, in accordance with the manufacturer's instructions. Peak accelerations and decelerations were retrieved from the GPS software (OpenField Console, Catapult Sports, Melbourne, Australia) as the highest value achieved during the test, the highest individual value achieved across the 17 matches for each player, and the highest value achieved during 85 training sessions for the same period for each player. That is, six data points were extracted for each player: the peak acceleration and the peak deceleration during pro-agility test, matches, and training sessions.

Statistical analysis

All statistical analyses were performed in jamovi (192,193) and Microsoft Excel (version 16.68, 2022, Microsoft Corp., Redmond, WA). Peak accelerations and decelerations are presented as mean ± SD. For each activity (pro-agility test, matches and training sessions), the coefficient of variation (CV) was calculated as CV = (Standard Deviation / Mean) * 100. To compare the difference between test, match and training performance, a mean paired difference was performed. This analyzes compared within-subject efforts, with each player peak effort being compared according to the selected activity. For example, the peak acceleration of one player during the pro-agility test was compared with the peak acceleration during matches and training sessions for that same player. Cohen's (*d)* effect sizes were estimated to assess differences between test and match values and established as unclear (when CI crossed both positive and negative values), trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0) and huge (>4.0) with 90% CI (54,55).

Results

Peak accelerations were similar during matches (4.68 ± 1.09 $m \cdot s^{-2}$), training sessions (4.94 ± 0.23 $m \cdot s^{-2}$) and the pro-agility test (4.64 ± 0.24 $m \cdot s^{-2}$). Peak decelerations were similar between training sessions (6.62 ± 0.39 $m \cdot s^{-2}$) and matches (6.04 ± 1.31 $m \cdot s^{-2}$) but the pro-agility test showed smaller magnitudes (4.71 ± 0.35 $m \cdot s^{-2}$). Overall, decelerations magnitudes were higher than accelerations magnitudes during all activities. Peak efforts CV were lower during the pro-agility test (CV: 5.2% and 7.4% for acceleration and deceleration respectively) and training (CV: 4.6% and 5.9% for acceleration and deceleration respectively), than during matches (CV: 23.3% and 21.6% for acceleration and deceleration respectively). Mean paired differences are presented in Table 21 and represented in Figure 33.

Table 21. Mean paired differences [90% CI] of peak accelerations and decelerations occurred during the pro-agility test, matches and training sessions, with effect sizes [90% CI].

	Acceleration	**Deceleration**
CODS vs. Match [90% CI]	-0.19 [-0.51, 0.12]	1.31 [0.77, 1.86]
	d = -0.35 [-0.93, 0.19][U]	*d* = 1.27 [0.82, 1.85][L]
CODS vs. Training [90% CI]	0.29 [0.20, 0.38]	1.92 [1.73, 2.12]
	d = 1.19 [0.79, 1.72][M]	*d* = 4.80 [3.87, 6.21][H]
Match vs. Training [90% CI]	0.30 [0.10, 0.50]	0.61 [0.05, 1.17]
	d = 1.09 [0.38, 1.96][M]	*d* = 0.58 [0.13, 1.10][S]

CODS=Change of direction speed; U=Unclear effect size; S=Small effect size; L=Large effect size; H=Huge effect size.

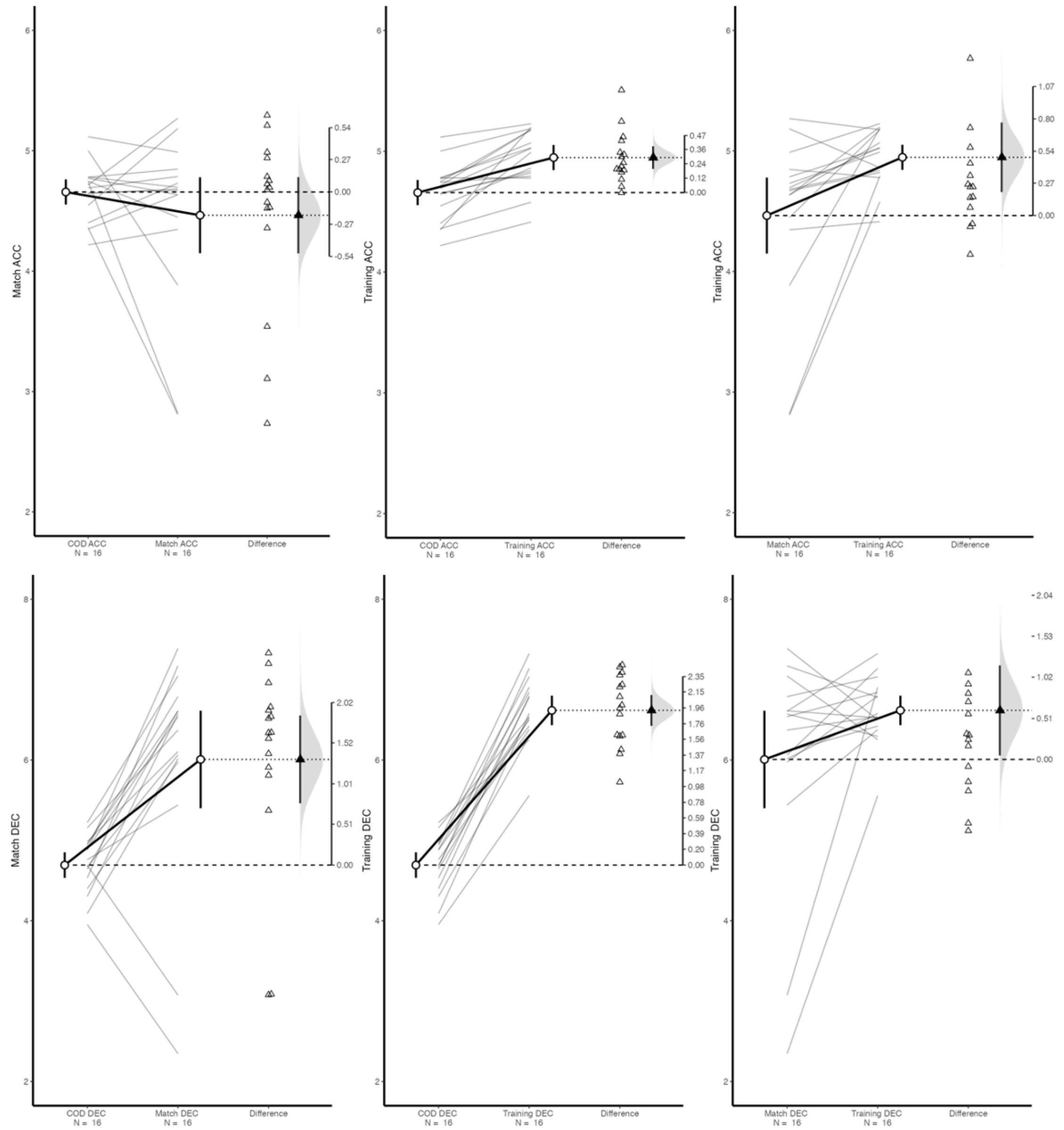

Figure 35. Paired mean differences [90% CI] between match, training and change of direction speed test (Pro-agility test: 5-10-5) regarding maximal registered accelerations and decelerations. ACC=acceleration; DEC=deceleration; CODS=change of direction speed.

Discussion

This study aimed to evaluate the peak accelerations and decelerations differences between one CODS test (pro-agility), matches and training sessions. The first finding of this study was that peak acceleration registered during matches was almost equal to the one registered during the CODS test and very similar to the one registered during training sessions (both with unclear effect sizes). However, the peak deceleration registered during the CODS test differed largely from the peak value of matches and hugely from training sessions. As so, it appears that training sessions are a better predictor of players peak values expression during matches.

With CODS tests, practitioners usually assess how fast each athlete can perform a specific COD with specific cutting angle(s). The specific cutting angle plays an important role in players' performances as higher cutting angles elicit higher braking forces, influencing both the approach velocity and exit velocity (10). For example, if a player encounters a 180º COD, he or she would need to powerfully decrease and increase his/her velocity, showing slower velocities at the cutting angle, in comparison with 45º cutting angle, where limited braking forces are required (10). In our study, players achieved practically the same peak acceleration during the pro-agility test than during matches. This is a novelty finding, providing information to practitioners that could use this test to assess and prepare players for competition demands. For instance, since sprinting, plyometric and resistance training improve the pro-agility performance (310), players could potentially benefit from those improvements during the competition period.

However, similarities between peak efforts registered during the pro-agility test and matches remains solely with accelerations (Figure 33). Decelerations differ largely between assessments which is probably justified by the unpredictability of matches, which is absent during CODS tests, and by players self-protecting themselves during the preseason period. For instance, Hader and colleagues (41) presented a peak deceleration of 3.00 $m{\cdot}s^{-2}$ during a 90º COD task, an effort magnitude higher than the registered during a 45º task (1.12 $m{\cdot}s^{-2}$), but which is considered by some authors as moderate (194). Considering this magnitude effort increase with the cutting angle, the peak deceleration registered in our study during the pro-agility test in unsurprising. Moreover, one potential strategy to elicit higher deceleration magnitudes could be expose them to an unplanned stimulus. Other strategy could be to assess peak decelerations during training sessions because match and training values presented only small differences in our study. However, it important to keep in mind that, ideally, training sessions should prepare players for match demands. That is, a chronic exposure of players to higher loads during training sessions may protect against acute spikes during matches, while inducing physiological adaptations (8,129,311). As so, achieving higher effort magnitudes during training sessions, is most probably desirable to ensure that protecting effect. Therefore, to ensure that players are prepared for matches, peak decelerations should be monitored during both matches and training sessions.

Future research with different players and different teams would contribute to a more definitive conclusion regarding the peak accelerations and decelerations similarities during CODS tests, matches and training sessions. Additionally, with technologic developments, future research could use equipment with higher measurement accuracy for peak efforts (45). Nevertheless, the peak values registered in our study are within the peak values registered in acceleration (235) and deceleration (203) field tests.

Conclusions

Our study shows that CODS tests may provide additional information to practitioners, as peak accelerations, and decelerations. This information can be compared to match and training efforts to assess players capabilities, especially considering matches, because peak accelerations retrieved during tests and matches are almost equal. However, peak decelerations differed largely and hugely between the pro-agility test and matches and training sessions, respectively.

Practical Applications

Practitioners can assess if training strategies are eliciting the desired effect on players. However, decelerations registered during the pro-agility test differed largely and hugely from matches and training sessions respectively. In this regard, the pro-agility test may lack the unpredictable perspective to elicit higher decelerations as occur during matches. Finally, practitioners are encouraged to provide unpredictable COD situations during training sessions to ensure that players are prepared to cope with match acceleration and deceleration demands.

CHAPTER V: GENERAL DISCUSSION

5.1. The challenge of monitoring accelerations and decelerations demands in soccer players

The importance of monitoring accelerations and decelerations has recently increased (5,6) due to the considerable contribution to player's total load (126) and to the importance of the ability to rapidly change speed (184). However, although several papers have investigated accelerations and decelerations demands on soccer players, some challenges still exist. Specifically, the intensity thresholds and minimum effort duration intervals are mainly arbitrarily chosen (13,194). This potentially raises issues regarding comparisons between studies, complicating definitive conclusions.

Considering the findings of the study III, establishing a minimum effort duration can alter the registered demands, especially decelerations efforts, as peak decelerations occur at very short time windows (0.1-0.2 seconds) (Figure 11). As so, high-intense decelerations can be disregard, impacting players' wellbeing, by increasing injury risk, muscle soreness and fatigue (20,188). This was previously highlighted, with authors reporting that small changes in minimum effort duration significantly affect the detected number of accelerations (17), recommending that accelerations and decelerations should be counted until the rate of these movements reach 0 $m{\cdot}s^{-2}$ (13).

Additionally, while accelerating from standing starts can require a minimum duration to achieve significant intensity, accelerating from very high starting speeds does not (24). One understandable concern could be the potential registered noise by not applying a minimum effort duration. That is, an insignificant movement can result on a registered effort, even if it had an irrelevant impact on player efforts. Be that as it may, a potential solution to this problem, could be ignoring efforts exclusively if they represent an insignificant intensity. For instance, in the study IV, we found that most very low intensity (<25%) accelerations and decelerations started predominantly from low starting speeds (< 5 $km{\cdot}h^{-1}$) (Figure 15). This means that these efforts predominantly represent insignificant displacements. Moreover, applying these relative intensity thresholds, considers the effort starting speed and the individual characteristics – two problematics of the accelerations and decelerations monitoring process (19,20,23).

One important adaptation to the initial percentage intensity proposal (24), is to consider the real-scenario context, by assessing peak efforts as the maximal efforts achieved during training sessions – or matches. The initial proposal (24) has assess peak acceleration with field tests, but decelerations fields tests are usually absence or performed with novel technology (inaccessible to several clubs) (203). Additionally, field tests can mislead practitioners with players failing to replicate tests performances during matches (205,206).

5.2. The role of acceleration and deceleration in speed displacements

Speed displacements are usually measured independently of accelerations and decelerations efforts when quantifying players' load. As discussed in study I, researchers and practitioners assess players' load with different measurement methods. Within these methods, displacements at certain speed thresholds are widely applied to categorize training or match demands (19). However, to achieve a specific threshold, players need to increase their speed (accelerate); and similarly, to return to a low-speed interval, such as walking, players also need to decrease their speed (decelerate). Regarding the most common sprint threshold (> 25.2 $km{\cdot}h^{-1}$) (279), the study IX showed that players achieve that speed with very short accelerations and from high starting speeds (> 20 $km{\cdot}h^{-1}$) (Figure 28) Similarly, as seen in study X, players reach their match peak speeds with moderate speed changes occurring 4 seconds before the peak effort (Table 20). These two studies provide interesting insights regarding how players reach high speed magnitudes. That is, accelerations as seen in maximal speed field tests (267), may be rare during competition. As so, field tests may place soccer players at deceitful expectations, being that failing to reach similar speeds (205,206) or by assessing efforts differently as they occur during competition.

Interestingly, according to the findings of study VIII, competition can provide or restrain opportunities to soccer players reach their peak efforts. For instance, even if a player achieves a high-performance during field tests, that same player can face contextual difficulties to express his or her capacities (Table 17). Adding to the discussed above, considering the real-scenario context can provide interesting information throughout the physiological demands analyzes. This strategy was applied across the different studies that compose this thesis, which showed interesting and novelty findings.

During the study II (systematic review) construction, four categories were introduced to help organize the collected information about training acceleration and deceleration demands: training drills, training drills variables, training schedule and playing position. Shortly, training drills refers to different exercises used across training sessions; training drills variables refers to different exercise' adaptations, such as increasing or decreasing number of players or the pitch size during SSG; training schedule refers to different calendar or time periods selected to analyze data; and playing positions refers to the different playing positions seen during matches. This categorization can help identify information gaps in current research, guiding future research projects in this topic. This thesis was developed with that approach in mind, trying to fill some information gaps without deviating from the main objective. Specifically, within the training drills category, the major topic relates to SSG demands, while in practice different exercises are used. As so, by investigating acceleration and deceleration demands during different, but common, drills such as rondos can provide new insights to practitioners. Additionally, different drills are also used as different warm-up strategies, which is often disregarded during research. Finally, within the playing positions category, GK are often inconsiderate during the demands monitoring process, but, as showed in study V, GK may face different demands across their performances, and both practitioners and researchers should monitor this position as well.

One of the most important findings across the studies V to VII, was that acceleration and deceleration demands may differ as the effort starting speed changes. For example, SSG (4 vs. 4) elicited more accelerations (> 2 $m{\cdot}s^{-2}$) then friendly matches (152). In the study VI, the same SSG format (4 vs. 4) elicited more low intensity accelerations than competition matches (moderate effect size), but less high intensity accelerations (moderate effect size) (Figure 21). This can be probably explained by the efforts starting speed, since acceleration capacity decreases as the starting speed increases (24). Since soccer players struggle to achieve high-speeds displacements during SSG, accelerations starting at higher speeds would be rare, decreasing the number of high-intensity efforts, if the effort starting speed is considered. A similar finding was registered when comparing rondos with matches, probably by the same reason as SSG – less space to achieve high-speed displacements. Another example of this, was found in the study VII, which compared different warm-up exercises. In this study, the speed exercise elicited higher demands, especially considering the efforts starting at high-speeds (> 20 $km{\cdot}h^{-1}$). Finally, the study V, that compared different GK exercises, reported that integrating GK with their teammates can result in more high-intensity accelerations and decelerations than the complementary work, but significant less low-intensity efforts than specific exercises (huge and large effect sizes) (Figure 20). As in the previous examples, the ability to reach high-speed displacements impacts the intensity demands of accelerations and decelerations. This highlights the need to consider starting speeds when assessing accelerations and decelerations, as to consider that high speeds are achieved with accelerations and departed from with decelerations.

Before considering the effort starting speed, it is necessary to established speed thresholds. We have chosen a 5 km·h^{-1} bandwidth because the common thresholds are applied arbitrarily (19). Additionally, since efforts starting at speeds > 30 km·h^{-1} are practically inexistent, we have merged the 25-30 km·h^{-1} and > 30 km·h^{-1} in one single bandwidth (> 25 km·h^{-1}). This maximal threshold is very similar to most commonly used sprint threshold: > 25.2 km·h^{-1} (279). However, this threshold may represent different demands to different players. As seen in the study IX, the 25.2 km·h^{-1} threshold represented an intensity of 71-91% of players' match peak speed (Figure 29). With the selected bandwidths, more intervals are created, reducing the possibility of missing individuality variation. Additionally, this approach was applied exclusively to calculate accelerations and decelerations intensities. To monitor high speed displacements, to established training load, a relative intensity classification is suggested, without the need of bandwidths.

As for the findings related to training exercises, the studies V to VI revealed important information. First, the study V showed that specific exercises elicited higher demands to GK than integrated and complementary exercises. However, since the three exercises provided different stimulus, varying exercises during GK training could be the best strategy. Although the comparison with other studies is difficult, a previous study reported insignificant differences between starters and non-starters GK's accelerations and decelerations efforts, while total distance differed significantly (30). This can potentially mean that competition has a smaller impact in the GK training week, than in other playing positions (194). Furthermore, during soccer matches, GK can go from passively watching the match, to be required to perform a sprint effort. Therefore, it is not surprising that GK perform much less distance sprinting than their teammates (4,216). Varying exercises can potentially prepare players for the unpredictable section of the match, and the potential accelerations and decelerations demands. Secondly, the study VI compared different training drills with competition, highlighting the match as the most demanding activity, except for efforts starting at high speeds (> 20 km·h^{-1}) registered during compensation exercises. This finding relates to previous research that identified matches as the most demanding activity (141). Interestingly, when comparing training exercises, unclear to small effect sizes were found for high-intensity efforts, with the exception of the comparison between SSG and technical drills (moderate effect size) (Table 15). This can be probably justified because high-intensity efforts were rare, especially considering the number of efforts occurred per minute. However, SSG elicited more efforts than the others exercises, similar to what has been previously reported (22,27,31,150).

Finally, the study VII compared different warm-up strategies during soccer training. This topic has been frequently discussed in the literature but focusing on specific protocols such as the FIFA 11+ (249–251). Although, practitioners often apply different warm-up drills which also need to be analyzed. For instance, when analyzing a female national team, a study reported more accelerations per minute during warm-up sessions than during SSG, but similar number of accelerations per minute between warm-ups and matches (34). In the study VIII, warm-up drills were divided as reaction, run and speed, with the latter eliciting higher demands than the others two drills, especially considering efforts that started at higher speeds.

These findings express the importance of considering relative and individualized intensity categories, referring the efforts starting speed as well. Additionally, by conducting demands' analysis with this strategy, differences between playing positions can also be expected to be found. For instance, during the study VI, comparing different activities, playing positions faced different demands, especially considering the effort intensity or starting speed. Overall, wide positions performed more high intensity efforts and efforts starting at higher speeds then central positions, during the different activities, including matches.

5.3 The role acceleration and deceleration in agility and change of direction speed movements

The terms agility and change of direction (COD) are often mixed when referring to specific sport movements. This confusion is mostly based on the presence of absence of an unpredictable stimulus. As so, if players move as a reaction to an unpredictable stimulus the term agility is applied (305). However, if players change their direction in a pre-planned route, the term change of direction speed (CODS) is applied (305). As so, agility is composed by perceptual and decision-making factors and the CODS that it induces (306).

The studies VII and XI presented interesting results regarding agility and CODS. By considering the previous definitions, the reaction speed exercise analyzed in the study VII, most likely emphasized the decision-making factors more than the displacement. If the displacement was to be the priority, high accelerations and decelerations demands would be reported (306,312). Considering the competition as reference, players also perform several COD movements (39), being exposed elevated braking forces to be able to reduce their speed to zero before changing direction (40). By registering more accelerations demands, the cited exercise focused on the reaction to a stimulus (Figure 23). Nevertheless, players also need to be quick at the displacement phase. And the importance of acceleration in CODS is showed in study XI, with the unclear difference between match peak acceleration and the pro-agility test peak acceleration (Figure 33). Interestingly, both training and matches peak decelerations were largely and hugely, respectively, higher than the test peak decelerations. Two potential justifications for this result are the unpredictability of competition, demanding decision-making ability from players, and by a potential self-protecting mechanism by players during the preseason period. In comparison, peak decelerations during COD tasks with smaller cutting angles (90º and 45º) were smaller (3.00 $m \cdot s^{-2}$ and 1.12 $m \cdot s^{-2}$, respectively) that the ones registered in the study XI (41). This makes sense because magnitude effort is expected to increase with the cutting angle (10).

5.4. Limitations

The monitoring process of accelerations and decelerations in soccer players is crucial. However, using absolute and arbitrary thresholds may compromise the individuality of players, and therefore, the retrieved data. We adapted the relative method by using peak values from real context (training and matches) and not from field tests. One may question if matches and training sessions show the true maximal capacities of players. However, as discussed in this thesis, field tests are performed with specific characteristics that are absent during the real scenario. Increasingly, since peak match speed appears to remain stable across a soccer season (CV= 4.9% within-players) (313), the peak value of one mesocycle would probably represent the peak value achieved during the season.

With the exception of the one systematic review, we only analyzed male soccer players, but differences between male and female players can be expected (314,315). Even with the notorious development in female soccer, the capability of using GNSS devices is still limited to some elite teams. With the expected increase in the number of teams that use these devices, scientific research would certainly meet that development. Regarding the number of athletes involved, the sample size, it is important to notice that when studying and researching in high-level players, researchers can be limited by the real scenario. That is, ideally, a minimum of available players would be pre-determined before advancing with the research (316,317). However, researchers also need to be careful in their approach to avoid interfering with the coaches and players usual process for two main reasons: first, when assessing demands during training sessions and/or matches interfering with the process can provide misleading findings, that could be a result of the interference; and secondly, the interference can fail to benefit all players and the team, leading to negative outcomes. Additionally, although this thesis comprised a wide sample, from different countries, different playing levels, different competitions, and different ages, individual performances registered during matches and during training sessions, can vary widely between teams. Each coaching staff uses specific tactics and strategies, preparing their players to improve their performance within those team characteristics.

Another important limitation concerns how data was collected. Although data was collected without my presence, procedures were strictly followed as intended for research purposes and conducted by experienced coaching staff. Increasingly, these procedures made possible the participation of elite teams, from different countries, which increases the sample diversity across the studies. Additionally, the coaching staff of all clubs were always available to clarify any procedure.

Finally, one important limitation concerns how data was treated, since some empirical studies used raw data (studies III-VII, IX, X), while others used filtered data (studies VIII and XI). However, it is important to notice that raw data was used in studies that assessed a group of efforts, interpreted as load. For instance, the number of accelerations or decelerations occurring for a specific drill, training session, or during a specific time-window (study X). This strategy allowed the creation of specific filters which intend to meet the challenges identified in the literature, while providing potential solutions. On the other hand, filtered data was used when peak values were assessed individually. That is, if the intention was to compare peak efforts, filtering data provided a simple and practical solution to collect a single value; if the intention was to compare the number of accelerations and decelerations during a specific test or activity, raw data would be selected instead.

5.5. Future research

This thesis presents a new approach regarding acceleration and deceleration efforts, showing the importance of this efforts in agility, running and change of direction movements. From here, it would be interesting to explore new paths with this approach. For instance, providing a contextual explanation of these efforts, could help coaches to better prepare and protect their players, by identifying certain movements. As an example, besides retrieving a specific acceleration and deceleration load, as number of efforts, practitioners would benefit if that report would be accompanied by how those movements (especially with high-intensities) occur. With this combined information, coaches can develop strategies to avoid or promote those strategies, according to each individual need.

With this new approach, different activities were assessed and reported. However, other activities can be explored in future research. Specifically, match demands of goalkeepers, warm-ups sessions from matches, different training exercises, and potential differences according to contexts (match location, match outcome, opposition level, and playing competition). Additionally, individualized acceleration and deceleration demands could be investigated if they predict a potential injury risk increase, and if they would be useful as a return to play monitoring strategy.

Although some of these paths can also be applied when researching at high-speed displacements, some additional research approaches can be beneficial for a broader understanding of these movements. For example, when monitoring acceleration and decelerations, it would be interesting to individualize high-speed displacements. As so, a comparison between methods (absolute and arbitrary vs. relative and individualize) could provide a clearer picture to practitioners on the importance of using individualize and relative thresholds for high-speed displacements. Finally, and considering the discussed pertinence of how field tests are currently applied, developing new testing protocols to evaluate players' maximum capacities could help practitioners individualize players' efforts.

5.6. Practical Applications when monitoring accelerations and decelerations

Considering the findings described in this thesis, we can better understand that accelerations and decelerations are fundamental efforts to monitor when considering external load assessment. However, the process of monitoring these efforts should consider the following:

- Monitoring players with absolute and arbitrary acceleration and deceleration thresholds disregards players' individuality. The same happens, when speed is established with absolute and arbitrary speed thresholds (studies I and II).
- It is preferable to neglect a minimum effort duration and filter very low intensity efforts (<25% of the maximum) to ensure that intense decelerations are included. (studies III and IV).
- Acceleration starting speed should be consider during the monitoring process, as it influences these efforts expression. However, starting speed has a smaller influence at the expression of decelerations (study IV).
- Soccer players perform different activities and if the monitoring process focuses exclusively at each activity as whole, training load may mislead practitioners by mixing activities with different intensities demands (studies V, VI and VII)
- Coaches should consider that matches provide opportunities and constrains to players capacity of expression their maximal speed, maximal acceleration, and maximal deceleration. (study VIII).
- Practitioners should provide leading sprints during training sessions and during field tests because soccer players achieve high speeds by accelerating while running (studies IX and X).
- Sprint field tests are performed in different conditions than what happens during competition and should be adapted by providing players space to a leading run before starting the test. (studies IX and X)
- The pro-agility test may be an interesting tool to assess players' peak accelerations due to the similarity with match peak accelerations. However, regarding peak

match peak decelerations, training sessions may be a better assessment tool. (study XI)

CHAPTER VI: CONCLUSIONS

The load monitoring process is progressively emphasizing accelerations and decelerations efforts. However, several studies have questioned some monitoring procedures. During this thesis, two main issues were addressed: the use of minimum effort duration and the efforts' intensity classification. As proposals to improve the accelerations and decelerations monitoring, we have proposed that efforts should be counted as soon as velocity increases or decreases until it reaches 0 $m \cdot s^{-2}$. As so, no minimum effort duration should be established as it can be detrimental to a correct load assessment, especially considering decelerations. From this strategy, an understandable concern may arise regarding the potential noise, which does not reflect a proper effort. Nevertheless, that "problematic" data can be posteriorly filtered by addressing efforts intensities. For example, by not establishing minimum effort duration, data can report an "acceleration" of 0.02 $m \cdot s^{-2}$, which would be most likely noise and not a proper acceleration. In some previous studies, some authors chose to filter efforts below a specific threshold (such as < 1 $m \cdot s^{-2}$ or < 2 $m \cdot s^{-2}$). Even better, if authors chose a relative and individualized threshold, those efforts would be automatically eliminated with the very low intensity (<25%). Increasingly, by adapting the intensity method as we propose, accelerations and decelerations efforts will consider the effort starting speed, in addition of a real scenario to evaluate peak efforts.

Besides monitoring accelerations and decelerations efforts, assessing how those efforts start can provide interesting information as well. First, since acceleration capacity decrease as the starting speed increases, a more precise intensity classification would be applied. Secondly, when comparing activities, a predominance of high-intensity efforts from a certain exercise can be due to the ability to reach higher speeds. However, to consider the effort starting speed, it becomes also necessary to established intervals. We used a bandwidth interval approach because the speed thresholds are arbitrarily chosen and differ between studies. It is important to keep in mind that these bandwidths were only applied to established starting' speeds and not to measure speed displacements. In that case, relativize and individualize intensities can also be the best approach, considering the player characteristics as well as the context. For instance, the most common sprint threshold (> 25.2 km.h-1) can represent 71% or 91% of match peak speed. This means that besides players' individuality, matches provide different opportunities to players express their capabilities. As so, demands should consider that instead of expecting that players achieve field tests performances.

After defining how training or match demands would be assessed, data can be collected and interpreted. By comparting activities, we found that match imposed higher demands than other activities. However, two interesting findings were also registered: combining SSG and compensation drills can provide a demand similar to match, regarding acceleration and deceleration; and rondos should be carefully used as it can elicit high intensity accelerations and decelerations demands. For instance, using rondos during warm-ups should be adapted to avoid excessive and undesirable demands. Additionally, and considering three common warm-up categories (reaction speed, continuous run, and speed drills) can provide different tools to practitioners: reaction speed can help players develop agility and CODS abilities, without imposing high decelerations demands; run drills can offer a relatively low demand to players, and be used during a compensation session (MD+1 session); and finally, speed drills expose players to high-intensity demands, being from accelerations and decelerations efforts, or from high-speed displacements.

Although we found higher demands placed to wide playing positions, practitioners should consider both the players' individuality and the expectation regarding the task demand. For example, central midfielders may report smaller demands due his or her capabilities, or due to the task not requiring high demands. Finally, even sudden stops appear to be rare following high-speed displacements, practitioners should prepare players to be ready to such a stimulus, avoiding an injury risk increase.

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