Simulated Soccer Game Protocols: A Systematic Review on Validated Protocols That Represent the Demands of the Game

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Abstract

Brito, P, Costa, J, Figueiredo, P, and Brito, J. Simulated soccer game protocols: A systematic review on validated protocols that represent the demands of the game. *J Strength Cond Res* XX(X): 000–000, 2023—Several laboratory and field testing protocols have been developed attempting to simulate the activity pattern and physiological demands of soccer. In the present systematic review, we aimed to analyze and discuss the appropriateness, strengths, and limitations of soccer-specific simulated tests. A systematic review of the literature was conducted based on the PRISMA guidelines. Studies conducted in soccer, simulated soccer match tests, and validated simulation protocols performed on-the-field or on a treadmill were considered. No sex restriction was applied, and age >18 years (i.e., adults) was considered. At least 1 outcome measure (e.g., neuromuscular performance, external load, internal load, or psychometric state) of post-simulated-match test or protocol had to be reported. Within the 14 studies included, the average methodological quality of the included articles was 0.61 ± 0.09 (mean ± SD) of 1. Overall, 9 validated protocols were identified. In the protocols, only amateur, university, or semiprofessional soccer players were analyzed. Only one study evaluated female soccer players. None of the studies evaluated the effect on performance over the 2–3 days after the protocol. Accelerations and decelerations, and changes in direction typically present in a game have not been clearly described in any protocol. Future research should address this issue and validate soccer-specific protocols in women.

Key Words: football, fatigue, physiology

Introduction

During a 90-minute soccer game, soccer players run about 10 km at an average intensity of about 80–90% of the maximal heart arate. Numerous explosive bursts of activity are required, including jumping, kicking, tackling, changes of direction, sprinting, changing pace, and sustaining forceful muscle contractions to maintain balance and control of the ball against defensive pressure (39). Although most distance is covered by walking and low-intensity running, high-intensity exercise periods are highly critical (5). Elite players can perform more than 10% of the total distance in high-intensity running and sprinting, with more than 250 high-intensity activities and sprints (26). Thus, soccer is a high-intensity and intermittent sport, which taxes both the aerobic and anaerobic systems.

The amount of high-intensity running and sprinting is highly variable from game to game and might be influenced by several factors, including the activity profile of the opponent teams, the playing level (32), and field position (26,32). However, during match play, the most intense periods are normally followed by periods when high-intensity exercise is reduced to levels below the game average.

In addition, the distance covered tends to be lower in the second half than in the first half of a match, and high-intensity activities tend to be lower toward the end of the match compared with the initial periods of the match (23). Notably, in the later stages of a game, blood lactate concentration declines, and plasma free-fatty acids increase, because of the decreasing intensity in game and changes in energy substrate (27). However, it is well accepted that soccer players may present physical and physiological signs of fatigue temporarily during the game and at the end of the game, and factors such dehydration, hyperthermia, glycogen depletion, and muscle damage may partially explain reduced performance during and after games (4,29).

Fatigue is a complex phenomenon that can be defined as a failure to maintain the necessary or expected strength, ability to maintain the intensity of a given effort over time. It can be influenced by the type of stimulus, type of muscle contraction, duration, frequency, and intensity, physiological and training status of the athlete, and environmental conditions (15). Thus, to better understand fatigue in soccer, several laboratory and field testing protocols have been developed attempting to simulate the activity pattern and physiological demands of the game. These protocols are useful because they allow for controlled and reproducible evaluations of the effect of various interventions (7,40).

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Several soccer simulations have been conducted on a nonmotorized treadmill (e.g., iSPT, contemporary soccer match-play simulation [CSP], and SMS+30), given the greater ease of implementation, but these protocols do not consider changes of direction, accelerations, braking, as well as technical actions and skills. Also, running on a nonmotorized treadmill provides a higher cardiometabolic stress compared with running on overground (42). Other protocols have been applied on the pitch (e.g., soccer simulation protocol [SSP], CST, SAFT90, BEAST90, T-SAFT90, and LIST), but the repetitive nature of these protocols (i.e., shuttle or circuit) could limit motivational aspects and compliance, even considering the potential ecological validity. Therefore, in the present systematic review, we aimed to analyze and discuss the appropriateness, strengths, and limitations of validated simulated soccer protocols.

Methods

Search Strategy

A systematic review of the literature was conducted based on the PRISMA guidelines (25). The searches for relevant content related to fatigue development during simulated soccer match tests or protocols were performed until the end of November 2021, using 4 electronic databases: PubMed, SPORTDiscus through EBSCOhost, Web of Science, and Scopus. In each database, the following descriptors were used: (1) [soccer OR football*] AND (2) [match* OR game* OR competit*] (3) [simulat* OR test* OR protocol* OR treadmill] AND (4) [fatigue OR tired* OR exhaustion OR weak*] AND (5) [valid* OR Reliab* OR Reproduc*] and NOT (6) ["American football" OR "Australian football" OR "Beach soccer" OR Indoor OR "Gaelic football" OR Rugby OR Futsal]. No sex and age restriction were imposed during search stage. Filters for "English" and "articles" were also applied. The reference lists of all articles were examined to identify further eligible studies. Articles published in ePub ahead of print within the abovementioned time frame were also considered. Additional searches were performed on Google Scholar when the full texts were not available in these databases and for articles found on ResearchGate™. Dedicated computer software (EndNote X20, Thomson Reuters©, New York, NY) was used for reference management, facilitating deduplication and screening steps.

The PICOS approach of the current investigation can be detailed as follows: Population: soccer players; Intervention: protocols on fatigue development; Comparators: soccer matches; Outcome variables: dependent variables were changes in biochemical, neuromuscular, and perceptual measures; Study design: observational studies with a before-after intervention (i.e., simulated soccer match tests or protocols).

Selection Criteria

Inclusion Criteria. We opted to include articles if they filled each of the following criteria: (1) original article; (2) abstract available for screening; (3) published in English language; (4) published/ahead of print up to and including November 2021; (5) in a scientific-indexed peer-reviewed journal (i.e., abstracts published in conference proceedings, books, theses, dissertations, reviews, systematic reviews, and meta-analyses were not considered); (6) studies conducted in soccer; (7) simulated soccer match tests or validated simulation protocols (on-field or treadmill); (8) included at least 1 outcome measure of post-simulated-match test or protocol, such as neuromuscular performance, external and internal load, or psychometric state; (9) no restrictions regarding the date of publication were imposed other than those described in item 4; (10) no sex restriction was applied, and age >18 years (i.e., adults) was considered; and (11) studies reporting descriptive effects of soccer fatigue protocols on fatigue (validation studies).

Exclusion Criteria. Exclusion criteria included unrelated samples (e.g., referees or goalkeepers), articles that did not contain 1 of the descriptors cited in the search strategy in the title, abstract and keywords, and experimental studies.

Methodological Quality Assessment

Fifteen criteria were determined using the Delphi Scale and Downs and Black (12,24). The National Heart Blood Institute guidelines for qualitative evaluation of observational cohort and cross-sectional studies and before-after (pre-post) studies with no control group were considered (available in: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). The quality assessment was based on the reporting of study methods and results with answer categories being "yes," "partial," and "no" (Table 1). Summary scores (ranging from 0 to 1) were calculated as follows: Summary score = [(number of "yes" × 2) + (number

Table 1

Quality assessment criteria.*

		Scoring		
No.	**Items**	**0**	**1**	**2**
1	Was the study question/objective/hypothesis clearly described?	No	Partly	Yes
2	Are the characteristics of the subjects [participation level (e.g., amateur), training background (years of training), and training status (number or hours of trainings/match per week) included in the study?	No	Partly	Yes
3	Were eligibility/selection criteria for the study population prespecified and clearly described?	No	Partly	Yes
4	Was the intervention clearly described in the study?	No	Partly	Yes
5	Are the outcome measures [an external (e.g., time motion analyses and performance measures) and internal (e.g., RPE, heart rate, dehydration, DOMS, and biochemical measures)] clearly defined in the Introduction or Methods section?	No	Partly	Yes
6	Was the period of the season where the match/simulation take place stated (off-season/preseason/competitive season)?	No	Partly	Yes
7	Was the ground surface specified (grass/artificial turf/synthetic surface; in the case of laboratory treadmill protocols, it was scored as 2)?	No	Partly	Yes
8	Were the environmental conditions (temperature and humidity) described?	No	Partly	Yes
9	Were outcomes measured before and after?	No	Partly	Yes
10	Were outcomes measured after 24, 48 and 72 h?	No	Partly	Yes
11	Was the protocol compared with a match?	No		Yes
12	Were the statistical tests clearly described and appropriated?	No	Partly	Yes
13	Are the conclusions of study supported by results?	No	Partly	Yes
14	Was there a limitations statement in the study where possible confounding factors were highlighted?	No	Partly	Yes
15	Were there practical applications statements in the study?	No		Yes

*RPE = rating of perception exertion.

of "partial" × 1)]/(number of criteria × 2) (21). Studies were then classified as high (≥0.75), moderate (0.50–0.75), or poor (<0.50) methodological quality.

The revised Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS) was used to judge the risk of bias at study level (19). Risk of Bias Assessment Tool for Nonrandomized Studies contains 6 domains: selection of subjects, confounding variables, measurement of exposure, blinding of the outcome assessments, incomplete outcome data, and selective outcome reporting. Each study was classified as low risk, unclear, and high risk of bias (Table 1, Supplement Digital Content 1, http://links.lww.com/JSCR/A408).

Data Extraction

In each search in the databases, 2 evaluators (P. Brito and J. Costa) independently examined the articles' title, abstract, and keywords in the first stage of screening, according to the established inclusion and exclusion criteria. If any disagreements occurred, both authors discussed, examined the situation on a case-by-case, and determined the inclusion or exclusion of a given article. The agreement was reached after discussion among the authors in all articles included in the analysis. Cohen's kappa was calculated to assess the extend of agreement between reviewers for methodological quality assessment (kappa = 0.87, almost perfect).

Demographic details of the included studies were then extracted, including sample size, sex, age/age group of the subjects and the geographical location where the study was conducted. Methodological descriptions included type of simulated soccer test or protocol, format (pitch size, number of players a-side, movement patters, the amount of high-intensity running, the time spent with the ball, and the number of headers, shots, and passes, and whether a rolling substitute policy was adopted), configuration (duration and number of periods/circuits), measurement techniques/equipment, and the variables (i.e., biochemical, neuromuscular, and perpetual measures) used to characterize fatigue.

Only results on external and internal load and physiological data were analyzed. Quality and quantity of technical and/or tactical actions were not considered.

Results

Search Results

A flow diagram for the selection of the studies can be found in Figure 1. Overall, 385 records were retrieved through the initial search in the electronic databases. The removing of duplicates yielded 298 studies that were screened for the title. Subsequent abstract screening (298 records) led to the exclusion of further 236 studies. Consequently, the full texts of 52 articles were assessed for eligibility, with 38 articles being excluded.

The average methodological quality of the included articles was 0.61 ± 0.09 (mean ± SD) of 1, ranging from 0.43 to 0.73, with 1 article considered of low (≤0.50) methodological quality (Table 2).

All studies presented high risk of bias arising from the confounding variables, with the exception of Stone et al. (40), Page et al. (31), and Small et al. (37) that were classified as unclear, because of the lack of information on the training time that the subjects performed per week, despite being semiprofessionals, and Rhodes et al. (33) and Small et al. (38) were classified as low risk. The remaining studies were marked as high risk because of the competitive level (i.e., amateurs or university students), and no information was provided regarding the number of training sessions (Table 3).

Only 3 studies were marked as unclear arising from the blinding outcome assessment, since Bendiksen et al. (7), Barrett et al. (6), and Campbell et al. (9) analyzed 2 or more groups, and it was not clear whether the evaluators were blinded to the groups.

For incomplete outcome data, only 2 studies (6,17) were considered low risk. CST (7) and LIST (30) were considered high risk because of players excluded that were likely to have changed the outcomes (i.e., performance markers). The remaining studies were marked as unclear because it is not clear how many subjects were analyzed in the results.

Description of Included Studies

The general characteristics, main goals, and conclusions of the 14 studies included are shown in Table 4. Overall, 9 validated protocols have been identified. Briefly, within the 14 studies included, 4 had university students as subjects, 5 had semiprofessional soccer players, 3 had amateur soccer players, 1 had elite female soccer players, and 1 had trained soccer and rugby players. The sample sizes varied from 6 to 18 subjects, depending on study design. Study design varied from observational (7), test-retest (4), single trial design (2), and randomized and counterbalanced crossover design (2).

Internal and External Load—Physiological and Physical Markers

The outcomes of internal and external load monitored during and after the simulated soccer protocols are shown in Table 5.

The most monitored internal load markers were heart rate, blood, and muscle lactate. Only Rhodes et al. (33), Small et al. (37), Small et al. (38) (SAFT90), and Delextrat et al. (10) (Loughborough Intermittent Shuttle Test, LIST) did not evaluate heart rate during the simulated soccer protocol. Blood and muscle lactate were evaluated in 6 studies (1,7,17,30,31,40). The most reported match-induced muscle damage marker was creatine kinase (CK) (7,17,35). Myoglobin was monitored only in T-SAFT90 (35). However, only Lovell et al. (35) evaluated these markers after 24 hours.

The number of circulating leukocytes, neutrophils, monocytes, and lymphocytes was monitored by Lovell et al. (35). Harper et al. (17) evaluated inflammatory markers (Interleukin) and endocrine responses (cortisol). The rating of perception exertion (RPE) was evaluated in CSP (31), T-SAFT90 (35), SMS+30 (17), and LIST (9,10,30).

The impact on sprint performance was monitored over predetermined sprinting distances ranging from 12 to 20 meters. Sprint performance was evaluated during the simulated soccer protocol by Stone et al. (40), Bendiksen et al. (7), Williams et al. (44), Harper et al. (17), and Small et al. (37). Small et al. (37) also evaluated the kinematic parameters. Change of direction and countermovement jump (CMJ) were monitored during SSP (40) and SMS+30 (17), respectively. However, physical markers were evaluated during the protocols, but there was any record of evaluation after 24, 48, or 72 hours after the protocol.

Only Delextrat et al. (10) and Small et al. (38) evaluated the fatigue effect on the functional hamstrings-to-quadriceps ratio (Hecc:Qcon) in female and male soccer players, respectively,

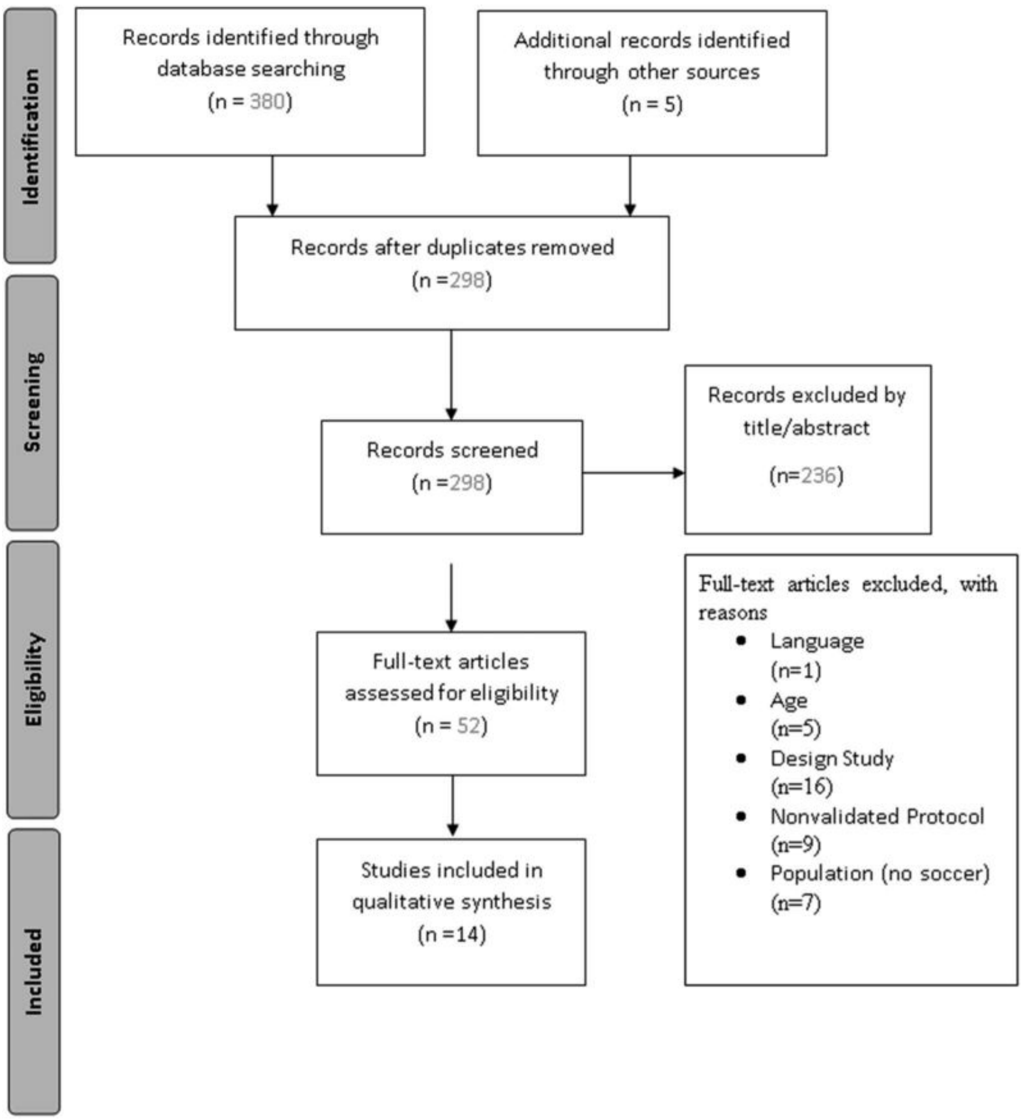

Figure 1. Flow diagram of the search and selection process for inclusion of articles.

Table 2

1. Question/Objective; 2. Characteristics of participants; 3. Eligibility/Selection Criteria; 4. Intervention; 5. Outcome measures; 6. Period of season; 7. Ground Surface; 8. Environmental conditions; 9. Outcomes measured before and after; 10. 24h, 48h and 72h; 11. Compared with a match; 12. Statistical tests appropriated; 13. Conclusions; 14. Limitations; 15. Practical applications.

Article	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Score
Stone et al. (40)	2	1	0	2	2	0	2	0	1	0	0	1	1	0	1	0.43
Aldous et al. (1)	2	1	0	2	2	0	2	0	2	0	0	1	1	1	2	0.53
Bendiksen et al. (7)	2	1	0	2	2	0	0	0	2	0	2	1	2	0	1	0.50
Barret et al. (6)	2	1	2	2	2	2	2	0	1	0	2	1	2	1	1	0.67
Page et al. (31)	2	1	2	2	2	2	2	2	1	0	0	1	1	0	2	0.67
Williams et al. (44)	2	2	2	2	2	0	0	2	1	0	0	1	1	1	2	0.60
Lovell et al. (35)	2	2	0	2	2	2	2	2	2	1	0	1	1	1	2	0.73
Harper et al. (17)	2	1	0	2	2	2	0	2	2	0	0	1	2	1	2	0.63
Nicholas et al. (30)	2	1	0	2	2	0	2	2	1	0	0	1	1	0	2	0.53
Delextrat et al. (10)	2	2	1	2	2	2	0	0	2	0	0	1	2	2	2	0.67
Rhodes et al. (33)	2	2	2	2	2	0	0	0	2	2	0	2	2	1	0	0.63
Campbell et al. (9)	2	1	1	2	2	0	2	2	2	1	0	1	2	1	2	0.57
Small et al. (37)	2	1	2	2	2	2	2	0	2	0	0	1	2	2	1	0.67
Small et al. (38)	2	2	2	2	2	2	0	0	2	0	0	1	2	0	2	0.63

Table 3

Evaluation of risk of bias using RoBANS.*

Article	Selection of subjects	Confounding variables	Exposure measurement	Blinding outcome assessment	Incomplete outcome data	Selective outcome reporting
Stone et al. (40)	Low	Unclear	Low	Low	Unclear	Unclear
Aldous et al. (1)	Low	High	Low	Low	Unclear	Unclear
Bendiksen et al. (7)	Low	High	Low	Unclear	High	High
Harper et al. (17)	Low	High	Low	Low	Low	Unclear
Page et al. (31)	Low	Unclear	Low	Low	Unclear	Unclear
Barrett et al. (6)	Low	High	Low	Unclear	Low	Unclear
Lovell et al. (35)	Low	High	Low	Low	Unclear	Unclear
Williams et al. (44)	Low	High	Low	Low	Unclear	Unclear
Nicholas et al. (30)	High	High	Low	Low	High	Unclear
Delextrat et al. (10)	Low	High	Low	Low	Unclear	Unclear
Rhodes et al. (33)	Low	Low	Low	Low	Unclear	Unclear
Campbell et al. (9)	High	High	Low	Unclear	Unclear	Unclear
Small et al. (37)	Low	Unclear	Low	Low	Unclear	Unclear
Small et al. (38)	Low	Low	Low	Low	Unclear	Unclear

*RoBANS = Risk of Bias Assessment Tool for Nonrandomized Studies.

immediately after LIST and SAFT90, respectively. Small et al. (38) also evaluated the angle of peak torque in the dominant leg. Rhodes et al. (33) examined the temporal pattern of recovery of 44 dynamic stability measures immediately after SAFT90, 24, 48, and 72 hours.

Only Campbell et al. (9) evaluated perceptual responses after the simulated soccer protocol (LIST) with wellness questionnaires and the relationship with neuromuscular performance (i.e., maximal voluntary contraction, CMJ, and 6-second cycle-ergometer sprint) immediately and 24 hours after LIST.

External Load and Performance Outcomes

The current systematic review identified 9 different simulated soccer protocols. Overall, 6 protocols were conducted on the pitch (SSP, CST, SAFT90, BEAST90, T-SAFT90, and LIST), and 3 were conducted in a nonmotorized treadmill (iSPT, CSP, and SMS+30). Physical, physiological, and performance markers were evaluated during and immediately after the protocol, but only 1 of the studies evaluated the effects on performance after 24, 48, and 72 hours (33).

Total distance and high-speed running were the most evaluated variables of external load. Total distance ranged between 8,017 and 12,200 m for BEAST90 and CSP, respectively. Harper et al. (17) also evaluated the extra time and observed an average of 14.400 meters. However, not all protocols evaluated high-speed running. Only iSPT (>15 km·h^{-1}), CST (>18 km·h^{-1}), SAFT90 (>15 km·h^{-1}), BEAST 90 ($>75\%$ maximal effort), T-SAFT90 (>15 km·h^{-1}), and LIST (sprinting >22.3 km·h^{-1}) considered high-speed running distance during the protocol, although they did not consider the same cutoff values to define high-intensity distance running. In fact, Hader et al. (14), in their review, evaluated the external load metrics that more effectively reflect acute and residual changes after match muscle damage and neuromuscular and perceptual responses. Running distance covered above 19.8 km·h^{-1} represented the most sensitive variable estimating postmatch changes in biochemical and neuromuscular responses. Also, strong evidence of a large correlation between high-intensity running (>14.4 km·h^{-1}) and muscle damage was reported after match, but this relationship became moderate after 24 and 48 hours.

Although high-intensity running plays an important role in fatigue, accelerations, decelerations, changes of direction, and jumps have a great impact on the development of fatigue. Also, these soccer-specific actions are commonly associated with decrements in neuromuscular performance and indicators of muscle damage after match (18). It should be noted that nonmotorized treadmill protocols may reduce the impact of accelerations (peak and magnitude), despite increasing the internal load (HR and perceived exertion) (13,42). On the other hand, structural differences in field-based protocols were observed. From 1 side, shuttle-running protocols may exacerbate on accelerations/decelerations/change of direction, whereas circuit-based protocols consider the various types of movement in the game. However, only T-SAFT90 (35) described the number of changes of speed, direction, and jumps (1,269 changes in speed; 888 changes in direction; 444 cutting maneuvers; and 12 jumps). In the remaining field protocols, no information has been provided about these components. LIST is also a shuttle-running protocol, but changes of direction are 180° turns, which may not be fully representative of the soccer game.

Maximal actions, such maximal sprints (15 and 20 m) and CMJ, were evaluated in SSP (40), CST (7), BEAST90 (44), SMS+30 (17), and SAFT90 (37). All showed a 1.9–5% decrease in maximum speed throughout the protocol. Only Harper et al. (17) evaluated maximum speed (20 m) and CMJ before the protocol, half time, 90, and 120 minutes; the same pattern in performed tests has been reported. However, the distance used for assessing maximum speed (15–20 m) may not be enough for players to reach maximum speed. If longer distances were used, differences in sprint ability could have been observed. Notably, Stone et al. (40) evaluated repeated sprints ability and sprinting agility; no significant changes throughout the protocol have been reported. In fact, in CST and BEAST90, the evaluation moments are incorporated in the protocol, which is not verified in the SSP. In SSP, the decrease in maximum sprint capacity throughout the protocol may also be caused by the repetition of the tests used.

Table 4

General characteristics of included studies, including quality assessment of the studies.*

Protocol	Study	Quality assessment	Population characteristics		Objectives	Study design	External load	Internal load	Conclusions
			Age (y)	Level					
SSP	Stone et al. (40)	0.43 Poor	20.8 ± 1.7	SP	To describe selected physiological and performance responses to an SSP.	Observational	TD = 11,196 m		SSP demonstrates good ecological validity, eliciting physiological, metabolic, and fatigue responses that are comparable with soccer match play.
iSPT	Aldous et al. (1)	0.53 Moderate	21 ± 2	U	To examine the reliability and validity of a novel NMT soccer simulation (iSPT) based on individualized speed thresholds.	Test-retest	TD = 9,002 ± 389 m HSR = 2,119 ± 146 m	HR (mean) (bpm) = 160 ± 8 [Bla] mean (mmol·L^{-1}) = 4.9 ± 1.6	iSPT is a valid and reliable soccer simulation, and the utilization of the variable run phase was also shown to successfully determine decrements in high-speed running capability.
CST	Bendiksen et al. (7)	0.50 Moderate	24.2 + 4.5	SP	To develop and validate a test that simulates the work and physiological response of players during a soccer game.	Observational	TD = 11,290 m HSR = 3,280 m	HR mean (%HR$_{max}$) = 85% ± 1% HR peak (%HR$_{max}$) = 96% ± 1%	Physiological response and the fatigue development during the CST represent those observed during a competitive soccer game. The rate of muscle glycogen utilization decreases progressively during a game and that the impaired sprint performance toward the end of game may be related to lowered muscle glycogen levels.
SAFT90	Barrett et al. (6)	0.7 Moderate	21 ± 1	U	To determine the internal (physiological) and external (motion analysis) loads of university players during competitive soccer match play. To create squad-specific soccer simulations using the SAFT90 model (Lovell et al., 2008). To validate the simulations from the players' internal (HR) and external (triaxial accelerometer) loads using their respective match-play data.	Observational	TD = 9,420 m HSR = 1,740 m	HR (mean) (bpm) = 162 ± 6 HR mean (%HR$_{max}$) = 85.9 ± 3.7	This study has demonstrated both the external and ecological validity of U-SAFT90.
	Rhodes et al. (33)	0.63 Moderate	22.94 ± 4.57	E	The aim of this study was to examine the temporal pattern of recovery of directional dynamic stability measures post–soccer-specific fatigue.	Observational			Directional dynamic stability of overall stability index (OSI), anterior-posterior (A-P), and medial-lateral (M-L) was shown to significantly deteriorate up to 48 h, as a result of soccer-specific fatigue.
	Small et al. (37)	0.67 Moderate	21.3 ± 2.9	SP	The aim was to examine the effects of the SAFT90 protocol on sprinting kinematics in consideration of movement mechanics previously detailed relating to hamstring injury risk.	Observational	TD = 1,078 m Sprinting (>20.4 km·h^{-1}) = 340 m Striding (>15 km·h^{-1}) = 1,500 m		The study indicates that exercise simulating the physiological and mechanical demands of soccer match play produced a time-dependent alteration in sprinting kinematics.
	Small et al. (38)	0.63 Moderate	21.3 ± 2.9	SP	The aim of this study was to investigate the effect of a 90-min multidirectional soccer-specific fatigue field test on eccentric hamstring strength and	Observational	TD = 1,078 m Sprinting (>20.4 km·h^{-1}) = 340 m		The SAFT90 produced a time-dependent decrease in eccentric knee flexor strength, and subsequently in the functional eccH:conQ strength ratio, and

Table 4

General characteristics of included studies, including quality assessment of the studies.* *(Continued)*

			Population characteristics						
Protocol	**Study**	**Quality assessment**	**Age (y)**	**Level**	**Objectives**	**Study design**	**External load**	**Internal load**	**Conclusions**
					hamstring:quadriceps muscular imbalances, as well as the angles of peak torque regarding implications for hamstring injury risk.		Striding (>15 km·h^{-1}) = 1,500 m		changes in knee flexor and extensor angles of peak torque.
CSP	Page et al. (31)	0.67 Moderate	22.5 + 3.5	SP	To quantify and validate the biomechanical and physiological response to a novel soccer-specific protocol characterized by clusters of high-intensity efforts; to consider the previous criticism of treadmill protocols as being unidirectional, and thus not replicating the mechanical load associated with match play.	Single trial design	TD = 12,200 m	HR (mean) (bpm) = ∼157–176	The treadmill protocol is based on the velocity profile of soccer match play and elicits a valid physiological and mechanical response.
BEAST90	Williams et al. (44)	0.60 Moderate	26.1 ± 4.6	A	To determine the validity and reliability of the BEAST90.	Test-retest	TD = 8,097 ± 458 m HSR = 2,257 ± 154 m	HR (mean) (bpm) = 166 ± 10 HR (peak) (bpm) = 183 ± 8 HR peak (%HR$_{max}$) = 85 ± 5	The BEAST90 protocol was found to be a valid and reliable simulator of soccer match play in terms of time, movement patterns, and physical demands.
T-SAFT90	Lovell et al. (35)	0.73 Moderate	23 ± 2	U	To examine the biochemical recovery 65 kinetics to a modified version of SAFT90, which included jumping and technical aspects 66 of soccer such as passing, dribbling, and maximal velocity shooting. To explore the external validity of the simulation by comparing the 69 observed responses with those reported in the literature after soccer match play.	Observational	TD = 11,100 m HSR = 2,040 m	HR mean (%HR$_{max}$) = 87% ± 5%	The study demonstrated the extended external validity of SAFT90 by complementing the protocol with ball interactions and jumping activities that better mimic match activities. T-SAFT90 induced acute physiological responses, together with muscle damage, endocrine and immune responses 24 h after the simulation that were synonymous in both magnitude and time course with previously published data after 11 vs. 11 match play.
SMS+30	Harper et al. (17)	0.63 Moderate	22 ± 2	U	To confirm the reliability of responses to extended periods of simulated soccer match play (i.e., 120 min). To investigate the influence of ET on performance and physiological responses.	Test-retest	TD = ∼14.4 km		SMS is a reliable protocol for measuring responses to 120 min of soccer-specific exercise, using a high time resolution approach to profile the reliability of responses. ET compromises performance and causes physiological perturbations that have acute and possibly chronic implications (i.e., in-match and after match).
LIST	Nicholas et al. (30)	0.53 Moderate	21.5 ± 0.9	T	The aims of this study were to describe selected physiological and metabolic responses to this intermittent high-	Test-retest	TD = 12.4 km	Part A ≈ 169 bpm Part B ≈ 175 bpm	The LIST protocol may be a valuable measurement tool in studying the effect of the physiological and metabolic

Table 4

General characteristics of included studies, including quality assessment of the studies.* *(Continued)*

Protocol	Study	Quality assessment	Population characteristics		Objectives	Study design	External load	Internal load	Conclusions
			Age (y)	Level					
					intensity running test, the Loughborough Intermittent Shuttle Test (LIST), and to assess the reproducibility of performance during this test.				responses to intermittent high-intensity exercise because it permits the measurement of performance and metabolic responses to free-running activities, while maintaining control over the exercise regimen and environmental conditions.
	Delextrat et al. (10)	0.67 Moderate	26.1 ± 4.6	A (women)	The aim of this study was to investigate whether a field test representative of soccer-specific movements induces fatigue, as expressed as a change in the functional Hecc:Qcon of the dominant and nondominant legs in female soccer players.	Observational		HR (mean) (bpm) = 159 ± 14 HR mean (%HR_{max}) = 85.6 ±5.0 [Bla] mean (mmol·L^{-1}) = 5.2 ± 1.4	The study showed that soccer-specific fatigue resulted in a significant decrease in the functional Hecc:Qcon ratio of amateur female players, with no significant difference between the dominant and nondominant legs.
	Campbell et al. (9)	0.57 Moderate	24.9 ± 3.8	A	This study aims to examine the dose-response relationship of 3 different exercise intensities on wellness responses and the time-course expression of perceptual variables and neuromuscular performance measures.	Randomized and counterbalanced crossover design		HR (mean) (bpm) = 174.9 ± 4.7	Perceived fatigue, readiness to train, and overall wellness demonstrated changes in time-course expression in isolation of competitive demands, indicating specific subscales may be used to assess the time-course expression of perceived physical readiness. However, wellness showed limited capacity to differentiate training intensities.

*SSP = soccer simulation protocol.

Table 5

Internal and external load responses during simulated soccer protocols.*

	Study	Variables	0 min	45 min	90 min	120 min	24 h	48 h	72 h
SSP	Stone et al. (40)	Heart rate (bpm)	—	162 ± 15	164 ± 12‡	—	—	—	—
		Blood lactate (mmol·L^{-1})	—	5.0 ± 3.0	4.5 ± 2.4†	—	—	—	—
		S-AR 15-m sprint (s)	—	2.71 ± 0.16†	2.71 ± 0.15†	—	—	—	—
		S-AR agility run (s)	—	5.72 ± 0.35	5.70 ± 0.28	—	—	—	—
		Repeated sprints (s)	—	2.78 ± 0.14	2.78 ± 0.15	—	—	—	—
iSPT	Aldous et al. (1)	Sprint distance (m)	—	497 ± 38	481 ± 41†	—	—	—	—
		Peak speed sprint (km·h^{-1})	—	21.1 ± 2.5	20.3 ± 1.7†	—	—	—	—
		HR mean (bpm)	—	168 ± 8	164 ± 8†	—	—	—	—
		Lactate (mmol)	—	5.3 ± 1.6	4.7 ± 1.7†	—	—	—	—
CST	Bendiksen et al. (7)	Plasma CK (U·L^{-1})	—	—	229 ± 48	—	312 ± 57	—	—
		Blood lactate (mmol·L^{-1})	—	4.6 ± 0.4 (average first half)	3.7 ± 0.3†	—	—	—	—
		Sprint velocity (m·s^{-1})	—	5.1 ± 0.4 Average first half	4.9 ± 0.7†	—	—	—	—
		Muscle glycogen (mmol·kg^{-1})	459 ± 15	—	235 ± 27 (↓50%)‡	—	—	—	—
		Muscle CrP (mmol·kg^{-1})	61.4 ± 2.8	17.1 ± 4.3‡ Minimum value	17.1 ± 4.3 Minimum value	—	—	—	—
		Muscle lactate (mmol·kg^{-1})	7.7 ± 1.9	31.2 ± 3.4‡ Maximum value	31.2 ± 3.4 Maximum value	—	—	—	—
		Plasma FFA concentration (μmol·L^{-1})	—	155–200 Average first half	437 ± 96	1,375	—	—	—
SAFT90	Barrett et al. (6)	Total distance (m)	—	9,420		—	—	—	—
		Walking (0.7–6.0 km·h^{-1})	—	2,760		—	—	—	—
		Jogging (6.0–15.0 km·h^{-1})	—	4,920		—	—	—	—
		Running (15.0–25.0 km·h^{-1})	—	1,500		—	—	—	—
		Sprinting (>25.0 km·h^{-1})	—	240		—	—	—	—
		Mean HR (bpm)	—	162 ± 6		—	—	—	—
		%HR$_{max}$	—	85.9 ± 3.7		—	—	—	—
	Rhodes et al. (33)	Overall stability index	2.42 ± 1.07	—	3.38 ± 1.42‡	—	4.22 ± 1.58‡	3.69 ± 1.62‡	3.00 ± 1.48
		Posterior-anterior	1.89 ± 1.01	—	2.42 ± 1.07‡	—	3.06 ± 1.06‡	2.68 ± 1.49‡	2.24 ± 1.29
		Medial-lateral	1.46 ± 0.49	—	2.07 ± 0.69‡	—	2.44 ± 0.94‡	2.14 ± 0.85‡	1.69 ± 0.52
	Small et al. (37)	Sprint time	—	↑5.54%‡	↑3.24%‡	—	—	—	—
		Maximum hip flexion angle	81.5 ± 9.8°	−14.8 ± 3.0°‡	68.6 ± 4.4°‡	—	—	—	—
		Maximum knee extension angle	7 ± 2.8°	—	20.9 ± 3.6°‡	—	—	—	—
	Small et al. (38)	Concentric quads peak torque (PT) (N·m^{-1})	235.0 ± 20.1	225.0 ± 22.4	228.1 ± 18.5	—	—	—	—
		Concentric hamstring PT (N·m^{-1})	140.8 ± 38.0	133.9 ± 27.9	131.4 ± 20.8	—	—	—	—
		Eccentric hamstring PT	—	↓5.2%‡	↓16.8%‡	—	—	—	—
		EccH:conQ ratio	—	↓8.9%‡	↓15%‡	—	—	—	—
		ConQ angle PT	—	↑5.5%‡	↑5.0%	—	—	—	—
		ConH APT	—	↓20%‡	↓25.4%‡	—	—	—	—
		EccH APT	—	↑23.2%‡	↑26.2%‡	—	—	—	—
CSP	Page et al. (31)	Blood lactate (mmol·L^{-1})	1.13 ± 0.33	2.57 ± 1.28‡	3.21 ± 2.14‡	—	—	—	—
		Heart rate (bpm)	63 ± 5	165 ± 18‡	172 ± 15‡	—	—	—	—
		RPE (A.U.)	6 ± 0	12 ± 2‡	14 ± 3‡	—	—	—	—
BEAST90	Williams et al. (44)	Mean HR (bpm)	—	167 ± 11	164 ± 10†	—	—	—	—
		Peak HR (bpm)	—	185 ± 8	181 ± 9	—	—	—	—
		Heart rate (%peak)	—	86 ± 6	85 ± 5	—	—	—	—
		Sprint 12 m	—	—	↑4.7 ± 0.3%	—	—	—	—
		Sprint 20 m	—	—	↑1.9 ± 0.8%	—	—	—	—
T-SAFT90	Lovell et al. (35)	%HR$_{max}$	—	89 ± 5 Average first half	85 ± 7† Average second half	—	—	—	—
		RPE (6–20 AU)	—	15 ± 2 Average first half	18 ± 2† Average second half	—	—	—	—
		Creatine kinase (U·L^{-1})	151 ± 103	—	283 ± 178	—	812 ± 383‡	—	—
		Myoglobin (ng·ml^{-1})	40 ± 28	—	203 ± 121‡	—	81 ± 19	—	—
		Cortisol (μg·dl^{-1})	9 ± 2	—	13 ± 5‡	—	10 ± 2	—	—
		Leukocytes (per mm^3)	6,617 ± 1,631	—	11,250 ± 2,643‡	—	6,131 ± 1,315	—	—
		Neutrophils (per mm^3)	3,863 ± 1,108	—	7,787 ± 2,406‡	—	3,327 ± 855	—	—
		Lymphocytes (per mm^3)	2,332 ± 463	—	3,103 ± 1,050‡	—	2,366 ± 515	—	—
SMS+30	Harper et al. (17)	20-m sprint speed (s)	3.22 ±0.13	3.32 ±0.12	3.39 ±0.15	3.53 ±0.32‡	—	—	—
		CMJ (cm)	32.5 ±5.6	31.0 ±5.4	30.2 ±5.1	28.3 ±6.2‡	—	—	—
		Creatine kinase (U·L^{-1})	264 ±154	344 ±169	451 ±196‡	571 ±249‡	—	—	—
		HR mean (bpm)	—	163 ± 13	163 ± 11	163 ± 9	—	—	—
		RPE (6–20 AU)	—	14 ± 3	15 ± 3	17 ± 3‡	—	—	—

Table 5

Internal and external load responses during simulated soccer protocols.* *(Continued)*

	Study	Variables	0 min	45 min	90 min	120 min	24 h	48 h	72 h
		15-m sprint speed ($m\cdot s^{-1}$)	—	5.54 ± 0.27	5.37 ± 0.25	5.12 ± 0.39‡	—	—	—
		Blood lactate ($mmol\cdot L^{-1}$)	—				—	—	—
		Insulin ($pmol\cdot L^{-1}$)	170.6 ±130.9	176.3 ± 128.9	132.7 ± 100.1	77.5 ±50.0‡	—	—	—
		NEFA ($mmol\cdot L^{-1}$)	0.18 ±0.11	0.91 ± 0.43	2.01 ± 0.48	2.58 ±0.73‡	—	—	—
		Glycerol ($\mu mol\cdot L^{-1}$)	21 ±12	149 ± 50	315 ± 82	446 ±159‡	—	—	—
		Interleukin ($pg\cdot ml^{-1}$)	7.7 ±18.2	12.0 ± 20.3	12.8 ± 20.3	11.0 ±16.4	—	—	—
LIST	Nicholas et al. (30)	Heart rate (bpm)	—	172 ± 3	176 ± 3 (part B)	—	—	—	—
		RPE (1–10 AU)	—	(Part A) = 8	(Part B) = 10				
		Blood glucose ($mmol\cdot L^{-1}$)	—	6.4 ± 0.5		—	—	—	—
		Blood lactate ($mmol\cdot L^{-1}$)	—	6.2 ± 1.0		—	—	—	—
		Loss of body mass	—	2.3 ± 0.1 kg		—	—	—	—
		Walking relative time (1.54 $m\cdot s^{-1}$)	—	48.1%		—	—	—	—
		Sprinting relative time (6.2 $m\cdot s^{-1}$)	—	3%		—	—	—	—
		Recovery relative time	—	4.9%		—	—	—	—
		Jogging relative time (3.0 $m\cdot s^{-1}$)	—	24.7%		—	—	—	—
		Cruising relative time (3.83 $m\cdot s^{-1}$)	—	19.3%		—	—	—	—
	Delextrat et al. (10)	RPE (mean) (A.U.)	—	12.6 ± 1.3		—	—	—	—
		Peak torque (PT) quads dominant ($N\cdot m^{-1}$)	128.7 ± 29.2	—	126.8 ± 29.8	—	—	—	—
		PT quads nondominant ($N\cdot m^{-1}$)	115.2 ± 28.8	—	115.1 ± 34.5	—	—	—	—
		PT hamstrings dominant ($N\cdot m^{-1}$)	110.6 ± 26.8	—	91.3 ± 22.8	—	—	—	—
		PT hamstrings nondominant ($N\cdot m^{-1}$)	100.1 ± 25.3	—	91.7 ± 24.7	—	—	—	—
		Quads dominant/body weight (%)	204.9 ± 39.6	—	202.9 ± 49.3	—	—	—	—
		Quads nondominant/body weight (%)	183.2 ± 39.9	—	183.7 ± 53.5	—	—	—	—
		Hamstrings dominant/body weight (%)	177.2 ± 44.0	—	145.9 ± 36.9‡	—	—	—	—
		Hamstrings nondominant/body weight (%)	140.2 ± 42.0	—	146.9 ± 39.0‡	—	—	—	—
		Hecc:Qcon dominant	0.85 ± 0.15	—	0.73 ± 0.13‡	—	—	—	—
		Hecc:Qcon nondominant	0.88 ± 0.17	—	0.81 ± 0.15‡	—	—	—	—
	Campbell et al. (9)	sRPE (AU)	—	7.9 ± 1.2		—		—	—
		HR mean (bpm)	—	174.9 ± 4.7		—	—	—	—
		RPE (AU)	—	6.7 ± 1.4		—	—	—	—
		Total wellness	23.5 ± 2.87	—	19.1 ± 3.76‡	—	20.35 ± 3.54‡	—	—
		Fatigue (1–5)	3.0 ± 0.8	—	1.7 ± 0.5‡	—	2.2 ± 0.5‡	—	—
		Readiness to train (1–5)	3.2 ± 0.6	—	2.3 ± 1.0‡	—	2.7 ± 0.8	—	—
		General soreness (1–5)	2.80 ± 0.85	—	2.10 ± 0.61‡	—	2.25 ± 0.54	—	—
		Mood (1–5)	3.86 ± 0.31	—	3.55 ± 0.68	—	3.50 ± 0.57	—	—

*CMJ = countermovement jump; SSP, soccer simulation protocol; FFA = free-fatty acids; RPE = rating of perception exertion.

†Differences compared with half time ($p < 0.05$).

‡Differences compared with pretest ($p < 0.05$).

Silva et al. (36) observed substantial muscle function impairments for strength-related capabilities, including eccentric hamstrings peak torque, rapid force development, change of direction, and repeated sprint ability. The authors noted that physical performance can be changed up to 72 hours after a match and commented that evaluating these parameters only immediately after the protocol may not be enough to assume that the protocol can represent game-related fatigue. Delextrat et al. (10) did not observe differences in concentric peak torque on the quadriceps, and suggested that soccer players are used to experience repeated recruitment of the quadriceps, and this might result in specific neuromuscular adaptations to counteract fatigue. On the other hand, a significant decrease in relative peak eccentric torque developed by the hamstrings has been detected after LIST. This could be explained by the high proportion of type II muscle fibers in the hamstrings and the number of eccentric contractions of the hamstrings during powerful actions related with sprinting, jumping, or kicking the ball (10,37,38). Small et al. (38) also evaluated semiprofessional male soccer players and observed the same pattern, with a decrease on peak torque eccentric in the hamstrings and alterations on angle peak torque after SAFT90.

Rhodes et al. (33) showed a differing temporal pattern of recovery of directional dynamic stability after soccer-specific fatigue, displaying a return to baseline at 77.33 hours after the protocol. The authors argued that this may potentially increase injury risk, but Rhodes et al. (33) did not report such patter after a soccer match.

Regarding external load, it should be noted that although nonmotorized treadmill protocols do not take changes of direction and braking actions into account, it seems that shuttle-running protocols may exacerbate these actions. However, shuttle-running protocols might be more appropriate when the objective is to evaluate the effect of accelerations and changes of direction throughout the game, whereas circuit and treadmill protocols seem to be more suitable for replicating the distances covered in the game.

Internal Load and Physiological Markers

Heart Rate. HR measurement is common in soccer, and it has been validated as an indicator of workload in different types of exercises and soccer training sessions (11). Only 5 studies monitored HR during the protocol, and only 3 analyzed relative HR ($\%HR_{max}$). In SAFT90 (6) and CST (7), average HR was 86 and

85% of HR_{max}, respectively. Bendiksen et al. (8) and Barret et al. (6) compared HR response during competitive games and the CST and SAFT90, respectively, and no differences were observed. These simulations included backwards and sideways movements and soccer-specific technical elements (e.g., ball touches, jumps, dribbling, kicks, and headers [on CST]) that may cause a reduction of physiological cost of exercise compared with that associated with actual game. However, although both protocols incorporated accelerations, decelerations, changes in direction, backwards, and sidesteps, the model in which the different types of efforts are performed has not been clearly described.

During BEAST90 (44), SAFT90 (6), and iSPT (1), mean HR ranged between 160 and 166 bpm. Alexandre et al. (2) reported that mean HR during match play ranged between 165 and 175 bpm, both in competitive and friendly matches. Nicholas et al. (30) observed that mean HR ranged between 172 and 176 bpm, but the highest values were observed after part B of the protocol (designed to exhaust in 10 minutes). However, most studies were conducted in youth players, and just 1 study was conducted in professional players (~170 bpm). Actually, during a competitive game, average HR has been found to average 85% HR_{max}, and peak HR has been close to maximal (4). However, the time spent in each intensity category might differ, but this has been analyzed just in CST (7). Here, soccer players spent 65% of the time above 80% HR_{max}. However, the use of HR_{max} might not the best indicator to evaluate exercise intensity in soccer because it does not consider the relative magnitude of HR responses. Indeed, 2 players can have a similar HR_{max}, but they might possess different resting HR, which could induce different HR responses during training or match play (2).

Blood and Muscle Lactate

Blood lactate concentration might be useful for understanding variations in aerobic endurance; it could be argued that the higher the lactate threshold, the higher the average intensity a player could maintain during a match, without accumulating lactate (11). Notably, during games, average lactate is highly variable, but concentrations ranging from 2 to 10 mmol have been reported, with individual values peaking above 12 mmol (4). However, the intermittent nature of soccer leads to large variations in intensity and concomitantly in muscle and blood lactate values. However, the interpretation of lactate concentrations during high-intensity intermittent exercise should be taken with caution because both blood and muscle lactate are dependent on the activities performed just before the sampling (7). Also, blood lactate can be high, although muscle lactate concentration is relatively low (4), and lactate might not be a major cause that determines and explains fatigue in soccer.

Generally, the protocols included in the present review showed differences in blood lactate comparing with that reported for competitive games. Absolute blood lactate values have been reported for the iSPT, with average values of 4.9 $mmol \cdot L^{-1}$ and LIST (30) with average values or 6.2 ± 1.0 $mmol \cdot L^{-1}$. Moreover, blood lactate has been reported for the first and second halves for iSPT (5.3 vs. 4.7 $mmol \cdot L^{-1}$), CST (3.2 and 3.9 $mmol \cdot L^{-1}$), SSP (5.4 and 4.4 $mmol \cdot L^{-1}$), and Page et al.' simulated protocol (2.4 mmol for both halves). The intensity and sequence of repeated sprints in these protocols may have not been sufficient to lead for blood lactate peaks, although mean values were close to those verified in formal games. On the other hand, relative muscle lactate values have been reported only in CST, with mean values in the first 15 minutes and peak values during the protocol of 23.7 and 31.2 $mmol \cdot kg^{-1}$, respectively. Here, collections were made immediately after repeated sprint efforts. Notably, Krustrup et al. (20) reported 15.9 and 16.9 $mmol \cdot kg^{-1}$ after an intense period in first and second halves of match play, respectively.

For the analysis of heart rate and lactate concentrations, CST was the protocol that presented results closer to those observed in a game, not only in average values, but also after the most intense moments of the protocol, such as after repeated sprints. Therefore, CST might be appropriate to assess cardiorespiratory fitness and might be useful in situations such as for return to play after a long-term injury.

Creatine Kinase, Myoglobin, and Inflammatory Markers

Creatine kinase and myoglobin have been used has common biomarkers to study muscle damage and inflammation in sports. SMS+30 (17) and CST (7) evaluated CK, and T-SAFT90 evaluated myoglobin and CK.

SMS+30 is performed in a treadmill, and does not require explosive movements, such as maximal accelerations, sprints, and changes of direction. The eccentric contributions required for these acceleration-based movements are likely to explain the physical distributions attributed to exercise-induced muscle stress that were observed up to 120 hours after match (22). However, SMS+30 did not evaluate CK 24 hours after the game. However, despite the reports of CK concentrations at 120 minutes, care must be taken to expect the recovery time to be like a competitive game.

In CST (7), CK immediately after and 24 hours after the protocol was not significantly different from the corresponding values for a friendly match, which may indicate that the soccer-specific movements in CST caused a degree of muscle damage comparable with that of formal game. Silva et al. (36) showed moderate to very large increases in CK and myoglobin, peaking at 24 hours, but persisting until 72 hours after match for CK.

T-SAFT90 is a shuttle-run protocol requiring a very high load of accelerations and decelerations and changes in direction, which can cause more muscle damage. T-SAFT90 (35) showed absolute values and relative increases (6-fold) for CK. The results are in accordance with Thorpe et al. (41), which reported match-induced muscle damage with peak CK activity.

In any of these protocols, CK and myoglobin were not evaluated after 48 and 72 hours. Therefore, care should be taken to analyze whether the levels of muscle damage would be maintained in the days after the protocol. The physical nature of the game, with repeated high-intensity activities, changes of direction, accelerations, decelerations, jumps, kicks, shots, sprints, and tackles, typically induces muscle damage, leading to a marked inflammatory response and production of cytokines. These cytokines facilitate a rapid and sequential invasion of muscle by inflammatory cell populations that can persist for days to weeks, whereas muscle repair, regeneration, and growth occur (29). Interleukin-6 is produced in larger amounts than any other cytokine and plays an initial role in the cytokine cascade. Interleukin-6 peaks immediately after the match, but rapidly declines toward pre-exercise (29).

Harper et al. (17) showed an increase in interleukin-6 during SMS+30 (after 90 minutes and extra time), but the high *SD* suggests large variations within players. T-SAFT90 (35) showed leukocytes through proliferative response of lymphocytes and neutrophilia after T-SAFT90, but values returned to baseline after 24 hours. Mohr et al. (28) studied performance and inflammatory responses in response to 3 soccer games within a week. White blood count was doubled after game compared with baseline, but remained elevated on the first day of recovery after each game. Then, 48 hours were needed to normalized values to baseline. Contrary, after 24 hours after T-SAFT90, leukocytes, neutrophils, and lymphocytes returned to baseline. Romagnoli et al. (34) observed the same pattern in youth players, with white blood cells count returning to baseline 24 hours after the game. Also, a twofold increase in interleukin-6 after the game was reported but returned to baseline after 24 hours.

The protocols studied were capable of inducing muscle damage, as seen in a game, regardless of the type of protocol (treadmill, shuttle-running, and circuit). However, CST was the only protocol with assessments implemented after 24 hours, suggesting that CST is currently the most indicated protocol to assess muscle damage in the days after the protocol.

Glycogen and Muscle CrP, Plasma Free-Fatty Acids, and Glycerol

Glycogen plays a central role in energy metabolism during prolonged, intense intermittent exercise. However, only CST (7) assessed the effect of the fatigue protocol on muscle glycogen. In CST, muscle glycogen was not significantly different from a friendly match (188 ± 19 mmol·kg^{-1}). Actually, after CST, 80 and 84% of the slow-twitch and fast-twitch fibers, respectively, were completely empty or partly empty of glycogen, with corresponding values of 98 and 100% for the control game (7). The rate of muscle glycogen utilization during the first part of the protocol was significantly higher compared with the remaining periods. In addition, the net rate of glycogenolysis during the warm-up and the first 15 minutes of the protocol were at the least twofold higher than from 15 to 60 minutes and fourfold higher than during the last part of the protocol. This can be related to a progressive increase in fat oxidation as the game progresses (7). Notably, Bangsbo et al. (4) also showed that a significant number of fibers are depleted or partly depleted at the end of a game. However, muscle glycogen stores are not always depleted in a soccer game. Krustrup et al. (27) revealed the muscle glycogen concentration at the end of the game was reduced to 150–350 mmol·kg^{-1}, which is comparable with the results observed with the CST. Although not all fibers might be empty, this depletion might limit players to maintain the intensity in the final stage of the protocol, as it happens in the game.

The high-intensity bouts in soccer are characterized by being short (≤10 m) but frequent, with an estimated recovery of ~72 seconds between bouts (3). This repetition of high-intensity activities stresses the anaerobic system, particularly in respect to the capacity of ATP-CP system and the ability to resynthesize CP (43). However, it takes approximately 1–2 minutes for CP to be restored to 50% of pre-exercise levels and 3–4 minutes to be 90% restored (43). Therefore, this marker is closely related to the activity performed immediately before its assessment. Only Bendiksen et al. (7) evaluated muscle CrP during CSP. Muscle samples were obtained within 10 seconds after a sprint, and muscle CrP values were significantly lower (61.4 + 2.8 mmol·kg^{-1} at rest) and were lowered by 56% after 15 minutes (26.8 + 3.6 mmol·kg^{-1}) of CST. The minimum CrP level during CST was 17.1 + 4.3 (range 4–30) mmol·kg^{-1} than observed in other studies. Krusturp et al. (27) showed, after an intense period in the second half, higher values (22). However, the role of CrP in fatigue development is uncertain. Sprint performance was not impaired after 15 minutes of CST, despite muscle CrP concentrations were as low as those recorded at the end of the protocol.

Also, triglycerides were depleted during a game, whereas the lower-limb musculature uptake of plasma glucose and free-fatty acids (FFA) was increased (16). Increased FFA plasma concentration has been observed during the game, most markedly during the second half. This can be explained by the frequent periods of rest and low-intensity exercise in a game, which allows a significant blood flow to the adipose tissue (3,4,27). Also, elevated glycerol concentration can be explained by a high rate of lipolysis during a game, although the increases are smaller than during continuous exercise, which probably reflects a high turnover of glycerol (5). However, no significant differences were observed in plasma FFA during the recovery from CST and a control game. However, during CST, plasma FFA was decreasing, although after 30 minutes of the protocol, the values were as high as during the game. Blood samples were collected 5–15 seconds after a high-intensity run, where high lactate values were found, and this might have suppressed mobilization of fatty acids from the adipose tissue (27). A high rate of lipolysis is also supported by the elevated levels of glycerol. Harper et al. (17), during SMS+30, observed an increase of glycerol during the protocol. Krustrup et al. (27) observed higher values than during rest after intense periods in the first and second halves. Silva et al. (36) observed increased plasma glycerol and FFA, which shows the high aerobic requirements throughout a game, and extensive anaerobic demands during specific match periods.

CST was the only protocol that studied the evolution of energy substrates throughout the protocol, compared with a control game. It is, therefore, the most suitable protocol for this purpose.

Perceptual Measures

Rating of perception exertion (a.u.) was measured in CSP, T-SAFT90, SMS+30, and LIST and ranged between 14 ± 3 (CSP) and 18 ± 2 (T-SAFT90) after the second half. After LIST, RPE was 10 because the part B was design to cause exhaustion. Differences in protocol designs can explain the differences. CSP is a nonmotorized treadmill protocol and does not require accelerations, decelerations, and change directions; however, it does not have the same eccentric load as the LIST and T-SAFT90 protocols. However, some care is needed when comparing protocols because different scales are used.

Wellness questionnaires were applied after LIST (9). Three different intensities were applied in the protocol (low, medium, and high), despite significant changes in fatigue, readiness to train,the wellness score and in the correlation with performance markers, these were not able to show differences in the applied loads.

It is important to highlight some limitations inherent to the protocols reported in this systematic review. First, only amateur, university, or semiprofessional soccer players were considered. However, the conceptual design of some protocols was based on workload profiles assessed from professional soccer players.

Notably, only Bendiksen et al. (7) tested the CST protocol in elite male soccer players. However, soccer-specific protocols developed for women are lacking. Only Bendiksen et al. (8) applied an adaption of CST (CSTw); no meaningful differences were observed between CSTw and a competitive match regards to total distance, high-intensity running or sprinting, and physiological responses. In addition, CSTw showed similar responses to previously published data on women's soccer and the original CST for men. However, this study did not meet all inclusion criteria because the studied population was younger than 18 years. Thus, future studies should address this issue and validate soccer-specific protocols in women.

Also, 3 of 9 protocols were performed on a treadmill, which does not elicit the accelerations and decelerations and changes in direction typically presented during a match. Furthermore, the remaining protocols, despite having been performed on the field, did not clearly describe any acceleration-based actions. It will be important to understand the difference between protocols and the impact of these movements on muscle damage. In addition, none of the protocols evaluated the effect on performance over the 48–72 hours after the protocol.

Practical Applications

For daily practice, simulated-soccer protocols can be considered efficient, according to their characteristics, for assessing progress in return to play situations. Since validated protocols are defined circuits or blocks of time, it is possible to carry out parts of a protocol and test how the player responds over time. It is also possible to test how the player responds to the game load after the return to play period. For research, simulated-soccer protocols can be a valid alternative when there is no chance to perform a formal game. They allow for controlled and reproducible evaluations of the effect of various types of physical and physiological interventions.

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