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SYSTEMATIC REVIEW

Acute Effects of Warm-Up, Exercise and Recovery-Related Strategies on Assessments of Soccer Kicking Performance: A Critical and Systematic Review

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Abstract

Background A number of reviews have collated information on the impact of warming-up, physical exertion and recovery strategies on physical, subjective and physiological markers in soccer players yet none have solely analyzed their potential effects on components of kicking performance.

Objective To systematically analyse the influence of warm-up, exercise and/or recovery-related strategies on kicking performance in male soccer players and provide a critical appraisal on research paradigm related to kicking testing constraints and data acquisition methods.

Methods A systematic literature search was performed (until July 2020) in PubMed, Web of Science, SPORTDiscus, Scopus and ProQuest. Studies in male soccer populations, which included the effects of warm-up routines, physical exercise and/or recovery-related interventions, reported on comparisons pre–post or between experimental conditions and that computed at least one measure of kicking kinematics and/or performance were considered. Methodological quality and risk of bias were determined for the included studies. Constraints related to kicking testing and data acquisition methods were also summarized and discussed.

Results Altogether, 52 studies were included. Of these, 10 examined the respective effects of a warm-up, 34 physical exercise, and 21 recovery-related strategies. The results of eight studies showed that lower limb kinematics, kicking accuracy or ball velocity were improved following warm-ups involving dynamic but not static stretching. Declines in ball velocity occurred notably following intermittent endurance or graded until exhaustion exercise (three studies in both cases) without inclusion of any ball skills. In contrast, conflicting evidence in five studies was observed regarding ball velocity following intermittent endurance exercise interspersed with execution of ball skills. Kicking accuracy was less frequently affected by physical exercise (remained stable across 14 of 19 studies). One investigation indicated that consumption of a carbohydrate beverage pre- and mid-exercise demonstrated benefits in counteracting the potentially deleterious consequences of exercise on ball velocity, while four studies reported conflicting results regarding kicking accuracy. Most evidence synthesized for the interventions demonstrated moderate level (77%) and unclear-to-high risk of bias in at least one item evaluated (98%). The main limitations identified across studies were kicks generally performed over short distances (50%), in the absence of opposition (96%), and following experimental instructions which did not concomitantly consider velocity and accuracy (62%). Also, notational-based metrics were predominantly used to obtain accuracy outcomes (54%).

Conclusions The results from this review can help inform future research and practical interventions in an attempt to measure and optimise soccer kicking performance. However, given the risk of bias and a relative lack of strong evidence, caution is required when applying some of the current findings in practice.

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Key Points

Kicking ball velocity is negatively affected by intense physical exercise protocols (e.g. intermittent endurance or graded until exhaustion efforts) mainly without ball involvements while the effects of passive resting, such as during the half-time pause, did not affect velocity.

Although players are generally able to maintain kicking accuracy regardless of prior exercise demands, kicking accuracy and ball velocity can be enhanced through a warm-up routine including dynamic stretching modalities while consumption of a carbohydrate beverage can help maintain ball velocity following prolonged exercise.

To enhance the ecological validity of methods used to test kicking performance, future research should include additional task constraints such as kicks performed over longer distances, opponents, and a greater variety of targets.

1 Introduction

The ability to kick the ball is evidently an essential skill in the sport of soccer notably when attempting to score goals [1]. High standards of shooting performance are associated with increased odds of winning [2–4]. Monitoring kicking performance and identifying factors affecting this component of play are, therefore, important. Individual characteristics such as the maturity, skill level and gender of players can notably influence kicking ability [1]. Another key factor frequently reported to impact kicking is physical exertion (e.g. external load). Prolonged aerobic exercise [5, 6] and repeated high-intensity running bouts interspersed with short recovery intervals [7, 8] are shown to impair central buffer [9] and lower limb mechanical functioning [10]. However, authors reviewing the effect of physical exertion on technical aspects of play using controlled field tests have presented contrasting findings. In 2011, Russell and Kingsley [11] reported that exercise-induced fatigue significantly impaired shooting performance, although only three studies all conducted in male soccer populations were available at the time of writing. In comparison, a more recent meta-analysis of acute and residual match-related fatigue in soccer, including two additional studies, reported trivial-to-small declines in shooting outputs linked to exercise [12]. A range of protocols to induce fatigue and measure its impact on kicking performance have been employed in investigations in male soccer players [13] (e.g. intermittent endurance with [14–16] or without inclusion of ball skills [17–19] or intermittent high-intensity bouts [20, 21]) yet their effects have not been systematically reviewed.

In general, the capture of advanced information on kicking movement and ball kinematics in real-world competition settings lacks feasibility [11, 22, 23]. As such, research investigations typically employ controlled field or laboratory experiments to assess kicking performance (e.g. exercise-induced effects [11, 24]). However, the results obtained using controlled testing are questionable [25, 26], notably due to poor criterion validity and the task constraints commonly utilised across studies. Examples of constraints include kicking targets positioned in the goal centre and instructions not concomitantly indicating the need for ball velocity and accuracy [27, 28]. In addition, the inclusion of opponents [29, 30] and kicks performed using a rolling and not only a stationary ball are frequently not considered [11, 31]. Low sampling measurement frequencies also possibly produce distorted limb kinematics data [32] and simple notational-based outcome metrics for quantifying accuracy can lack reliability and sensitivity [11, 24]. While previous reports have critically appraised kick assessment methodologies, these were generally published approximately 1 decade ago [1, 11, 33–36]. Arguably, an up-to-date collation and critical evaluation of procedures utilised in studies examining key variables related to soccer kicking performance would help identify good practice for current research while generating practical applications [11].

Ensuring player readiness to respond to kicking demands in soccer can be enhanced by warm-up routines [37], while recovery prescriptions [38] or ergogenic aids [17, 18, 39] are commonly used in an attempt to counter fatigue elicited from exercise. A plethora of reviews have examined the impact of intervention strategies such as warm-ups [40–42] or recovery-related modalities during and following exercise [12, 43–46] on physical, physiological and perceptual performance markers in team sport athletes. Yet, to our knowledge, none have specifically collated and critically appraised the current evidence on the effects of these factors on components of kicking performance such as accuracy and ball velocity. For example, standard warm-up programs including only submaximal running followed by stretching and sport-specific drills are generally shown to be suboptimal and may even impair preparedness for physical tasks that are explosive in nature [41]. Again, the impact of such warm-up practices on goal-directed soccer skills such as kicking have not been examined collectively despite several original research papers comparing performance following different stretching routines in male soccer players [47–51]. Finally, research investigating the effects on kicking outputs of rest periods (e.g., breaks in play such as half-time) [52], commonly prescribed ergogenic (e.g. hydro-nutritional) interventions [53] or the time-course of changes in performance following exercise cessation has yet to be synthesised. This would help determine the role of recovery processes and their effectiveness in counteracting potential exercise-induced declines in kick outputs [11]. Therefore, to examine the acute effects of warm-up, exercise and/or recovery-related strategies on kicking performance, we systematically reviewed the current body of original research articles in soccer players and critically appraised the testing constraints and data acquisition methods.

2 Methods

Permission for this study was granted by the Institutional Human Research Ethics Committee of the São Paulo State University (#2650204). The work was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [54]. The protocol was registered (updated record pending publication) at PROSPERO (ID = CRD42018096942).

2.1 Search Strategy

Searches for relevant scientific studies on the influence of (#1) prior warm-up, (#2) physical exercise demands and (#3) recovery-related strategies on players' movement kinematics and performance during soccer kicking were conducted using five electronic databases (from inception to July 2020), namely PubMed/NCBI (United States National Library of Medicine), Web of Science Core Collection (Clarivate™), SPORTDiscus (EBSCO Industries Inc.), SCOPUS® (Elsevier B.V) and ProQuest® (ProQuest LLC). Additional searches were performed in Google Scholar (Google LLC) when the full-text was not available, allowing for inclusion of studies found in ResearchGate™. In all databases, pertinent descriptors were combined (Table 1) through a Boolean strategy, using operators 'OR' between terms of the same column, and 'AND' inserted between columns. Full description of input arguments used in each database is also provided (Electronic Supplementary Material Table S1). A dedicated computer software (EndNote X7.0.1, Thomson Reuters©, USA) enabled management of references.

2.2 Selection Criteria

2.2.1 Inclusion Criteria

Studies were included if they unrestrictedly met all the following criteria: (i) original article; (ii) with full-text and abstract available for screening; (iii) published/ahead of print up to and including the 30th July 2020; (iv) written in English; (v) published in an indexed peer-reviewed scientific journal. Conference proceedings, literature reviews, meta-analysis, books, theses, and dissertations were not considered. In addition, following the PICO (Population, Intervention, Comparison, Outcome) eligibility criteria [55], studies were included if they (vi) (P) referred to male footballers; (vii) (I) examined the effects of a warm-up (≤ 25 min) [42], exercise (i.e. when there was a previous warm-up in addition to a given exercise protocol), and/or recovery-related strategies (i.e. resting and/or ergogenic aids) [12, 43]; (viii) (C) reported comparisons pre- vs post-intervention or among experimental conditions and (ix) (O) included at least one outcome measure regarding biomechanical variables of kicking performance [ball velocity, accuracy (any quantitative metric indicating proficiency in ball placement in the goal/target)] and/or lower kicking limb movement kinematics [e.g. joint angular displacement, foot velocity], (x) obtained in a controlled experimental setup.

Table 1 PICO descriptors combined in the search strategy

Population	Intervention			Comparison	Outcome
Soccer	Warm-up[a]	Exercise[a]	Recover[a]	N/A	Kick[a]
Football[a]	Heat[a]	Fatigue[a]	Rest[a]		Shoot[a]
Association football	Stretch[a]	Match demands	Supplementation		Skill
11-a-side	Strength	Match-related fatigue	Cold water immersion		Technical
	Postactivation potentiation	Effort Running	Compression garments Massage		
	Pre-match		Electrical stimulation		
			Sleep		
			Post-match		

N/A not applicable

[a]Wildcard term

2.2.2 Exclusion Criteria

The qualitative synthesis was not performed for studies (i) including athletes from other football codes; (ii) special populations (players with cerebral palsy, amputees); (iii) without mention of the warm-up, exercise and/or recovery-related protocols used; (iv) providing match-related statistics to determine kicking performance; (v) examining validity of tests; (vi) where a ball was not kicked; (vii) assessing skills which required ball manipulation other than shooting actions; (viii) studying exercise consisting solely of cognitive/mental efforts, (ix) using measurements performed > 48 h following a recovery-related strategy intervention [56] and, (x) in studies including female players while in those including male and female players, only information pertaining to the male group was retained.

2.3 Methodological Quality Assessment and Risk of Bias

Risk of bias (RoB) of results or inferences were determined for each study using Cochrane Collaboration's Tool [57], taking into account the criteria of random sequence generation, allocation concealment, blinding of participants, personnel and outcomes, incomplete outcome data, selective outcome reporting and other source of bias. Each item was deemed as low, high or unclear risk. Review Manager software (RevMan, v5.3.5, The Cochrane Collaboration, Denmark) [58] was used to obtain the graphs of RoB. The methodological quality of included studies was assessed using 12 questions (Q1–12) modified from the checklist presented in Palucci Vieira et al. [59] in addition to three key components obtained from RoB analysis (random sequence generation, concealment of allocation and blinding of outcome assessors) [60]. For the criteria, a three-point scale was used (Electronic Supplementary Material Table S2). A sum of scores from all questions was subsequently computed ($\sum = 0–24$) and the values were then converted into percentages (0–100%). Studies were classified as having high (≥ 75%), moderate (50–74%) and low (< 50%) methodological quality [61]. Two evaluators (LV, FS) performed independent assessments. If discrepancies occurred, these were resolved in a consensus discussion with a third evaluator (EK). Methodological quality was not an inclusion/exclusion criterion.

2.4 Data Extraction and Codification

In the first screening stage, record titles, abstracts, and keywords were examined independently by two evaluators, according to the inclusion and exclusion criteria established, while a third senior researcher was asked to solve any disagreement that occurred between the two evaluators (same authors as described in Sect. 2.3). Inter-evaluator agreement for the current review was assessed using Cohen's kappa coefficient ($k_{mean} = 0.95$). After examination of the included full-text studies, data extraction was subsequently performed by one author (LV) following a structured script which included the following items [1, 28, 29, 32, 33, 62–77]: sample characteristics (number of participants, age, competitive level and playing position), environment where the data collection took place, type of ball used, software/equipment which measured outcome variables, acquisition frequency and instructions given to the participants on how to complete the kicking task. More specifically regarding the kicking task, the following constraints were also considered: trials, kick type, approach run parameters, target, goal size and whether opponents (defender and/or goalkeeper) were present. The extraction sheets were created and adjusted following pilot checking across ten studies randomly selected from those included in the current review.

Where mean and standard deviation values were reported, these were used to calculate mean percentage difference (MD) and standardised mean difference (SMD) [78]. When possible, associated 95% confidence intervals (95% CI) were also estimated for individual studies using the RevMan software [58]. When results were presented as figure(s), we implemented a custom-built algorithm in MATLAB® environment (The MathWorks Inc., USA) to estimate the real data [59]. In the absence of pertinent data on full texts, the corresponding authors were contacted. If available, p values were presented for the instances where it was not possible to compute SMD (e.g. due to insufficient information and lack of reply to our request). The treatment effects obtained (i.e. MD or SMD) refer to between-groups (e.g. intervention vs. control) and/or within group comparisons (e.g. pre- vs. post-intervention) [79]. The symbols > (greater than), < (lower than) and = (no difference) were used to summarize main findings [41]. When inferences about null-hypothesis significance test were omitted, the acronym "vs." (versus) was employed. Subgroup analyses were performed considering the type of intervention protocol, player age [adolescent (13–17 years-old) or adult senior (≥ 18 years-old)] [80] and competitive standard [elite (professional players, competing at national/international levels) or sub-elite] [81, 82].

2.5 Evidence Synthesis

To summarize the main results according to the level of scientific evidence provided, we used a classification adapted from van Tulder et al. [83]. Thereby, findings were deemed to represent 'strong evidence' (consistent findings observed among multiple high-quality studies), 'moderate evidence' (consistent findings observed among multiple moderate-quality studies and/or one high-quality study), 'limited evidence' (findings provided by one moderate-quality study and/or only low-quality studies), 'conflicting evidence' (when inconsistent findings were observed) or 'no evidence' (when there were no available studies). Consistencies and inconsistencies were determined, respectively, by ≥ 75% and < 75% of studies reporting results showing the same direction [84].

3 Results

3.1 Search Results

The entire search process resulted in 10,777 studies, plus 3 additional studies manually entered. Figure 1 presents a flowchart with all steps from initial search until inclusion. After duplicates were removed, 4397 studies remained on reference manager. Following on, non-relevant content was immediately excluded (e.g. non sport performance specific). After verification of the title, abstract and keywords, of the 2091 studies assessed for screening, 73 were deemed

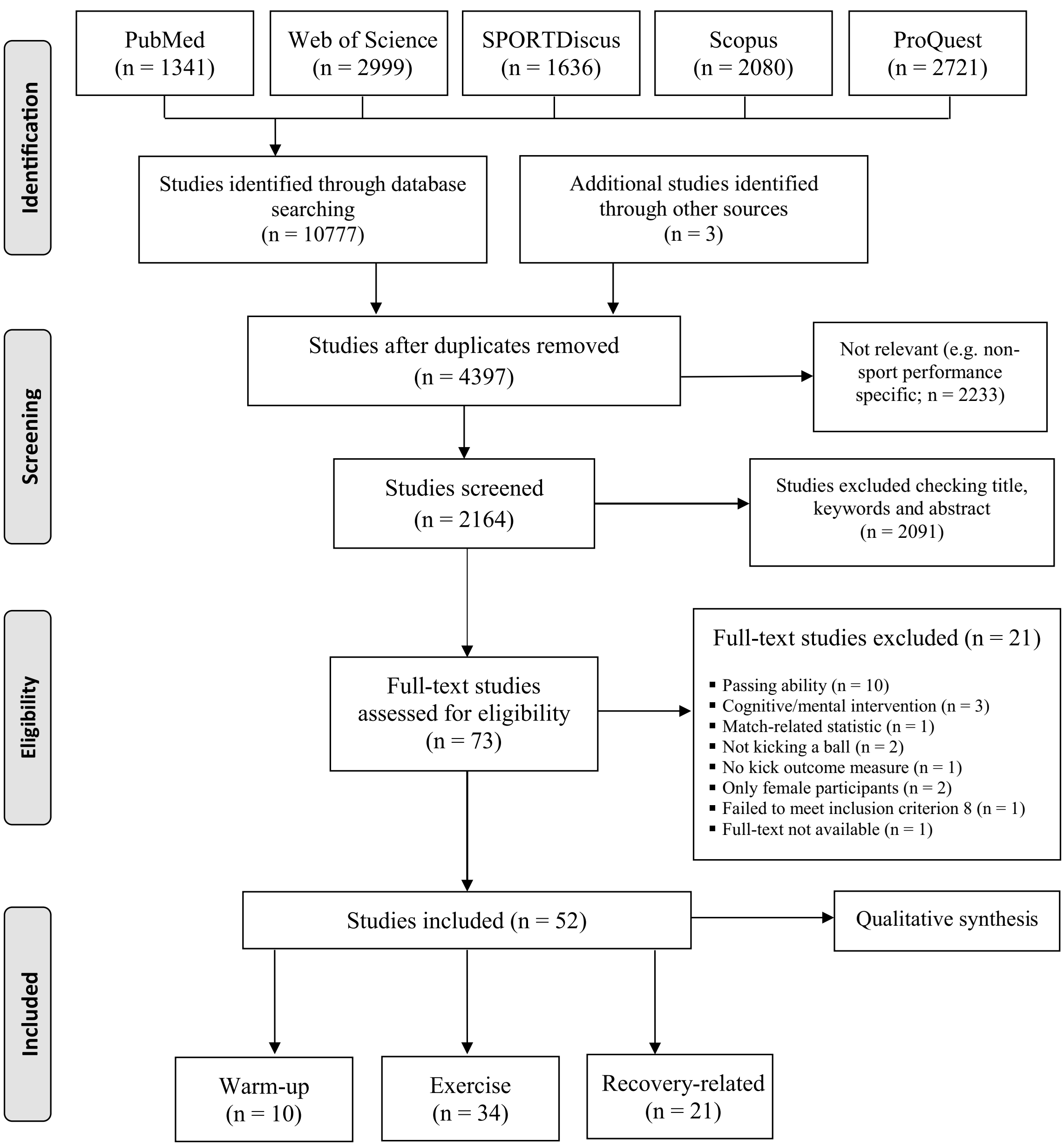

Fig. 1 Flow chart including literature search and selection steps following PRISMA statement

eligible. Additional reading of full texts determined 52 studies [13–21, 23, 37–39, 47–51, 64, 85–115] that were suitable for inclusion in the systematic review. Of these, 10 examined the effects of a warm-up (19%) [37, 47–51, 88, 90, 105, 108], 34 exercise (65%) [13–21, 23, 38, 39, 85–87, 89, 91, 93–97, 100–104, 107, 110, 112–114, 116] and 21 recovery-related strategies (40%) [14, 16–18, 38, 39, 48, 64, 85, 86, 91–93, 97–99, 106, 107, 109, 111, 115, 117].

3.2 Research Quality and Risk of Bias

Evaluation of the 52 studies selected showed a mean ± standard deviation rating of methodological quality equal to 63 ± 11% (Electronic Supplementary Material Table S3). With the exception of RoB items which were also used to evaluate methodological quality (described in detail below), the questions with the lowest and highest mean scores reached were Q4 (1.02 ± 0.64 points) and Q2 (1.96 ± 0.19 points), respectively. Risk of bias according to each key criteria are provided as percentages across literature studies (Fig. 2) and on an individual basis (Fig. 3). The largest RoB (23% of studies with 'high' RoB) [37, 38, 48, 49, 87, 88, 90, 97, 99, 104, 105, 109] was observed in 'selective reporting (reporting bias)' item and lowest RoB (100% of studies with 'low' RoB) was found regarding 'incomplete outcome data (attrition bias)'. The 'blinding of outcome assessment (detection bias)' entry demonstrated the greatest amount of uncertainty across studies (98% of studies with 'unclear' RoB), except for one study showing 'low' RoB [115]. Items also showing few studies with 'low' RoB were 'blinding of participants (performance bias)' (19%) [14, 17, 39, 85, 86, 92, 94, 106, 115, 117] and 'allocation concealment (selection bias)' (13%) [14, 39, 50, 51, 106, 115, 117].

3.3 Research Paradigm

3.3.1 General Information

A total of 947 players were evaluated in the included studies (320 youths), representing an average of 18 participants per study (range 5–174 players). Nearly half of the studies were published on or after 2015 and the majority dated from the last decade (Fig. 4). Details on demographic characteristics, the location where experiments took place and apparatus used in data acquisition are presented in Table 2. Investigations were conducted primarily on the football pitch (25%), in a laboratory setting (19%) or indoor/court (15%), while several (40%) did not specify the experimental location.

3.3.2 Experimental Approaches

Regarding the kicking task constraints adopted, 35% of studies examined players kicking a stationary ball, 15% a rolling ball, one used both [114], while the remainder (46%) did not provide any detail. The instep kick was predominantly analyzed (44%), while half of the studies did not indicate the region of the foot used to kick the ball. Regarding the approach run, approximately 37% of studies mentioned at least one characteristic of the run, 58% did not, or this was self-selected in several studies (Table 3). Instructions given to the participants were: to kick at maximal velocity without accuracy constraints (37%), hit the target without velocity constraints (25%), kick at maximal velocity and hit a target (13%), hit a target with maximal velocity (6%), maximal velocity and try to hit a target (8%), hit a target with realistic velocity (match specific) in one study [110] or instructions were omitted in 10%. The location at which players aimed their kicks included the entire goal (15%), only in its centre (25%), targets with multiple locations in the goal (15%) or only in the four corners (8%). No information on kicking target configuration was available in 37% of studies.

3.3.3 Data Acquisition

Ball velocity was determined in 65% of included studies, using a radar (50%), or a three-dimensional (3D) video kinematic system (41%; sampling frequency ranging from 50 [14, 16, 37] to 500 Hz [23]) using trajectories derived from one [37] to eight markers [98] positioned on the ball's surface or equation estimates using foot velocity data as

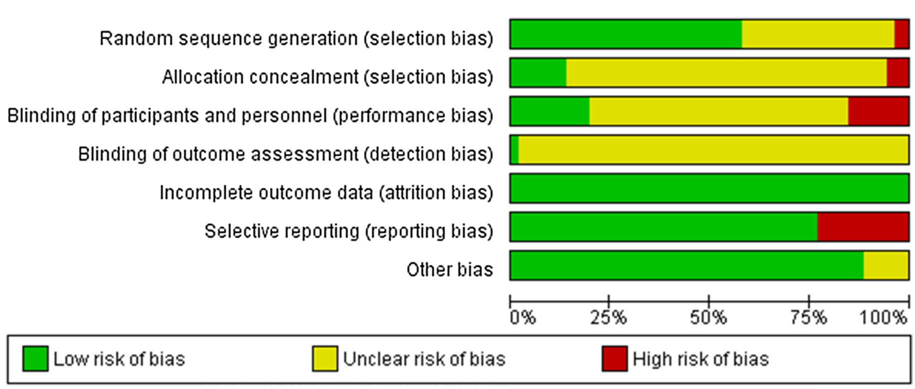

Fig. 2 Risk of bias graph considering all studies pooled

Fig. 3 Risk of bias for individual studies and according to the different criteria assessed. (+) = low risk; (?) = unclear risk; (−) = high risk

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Abbey and Rankin [85]	+	?	+	?	+	+	+
Abt et al. [86]	+	?	+	?	+	+	+
Ali et al. [17]	+	?	+	?	+	+	+
Amiri-Khorasani [49]	?	?	?	?	+	−	+
Amiri-Khorasani and Ferdinands [37]	+	−	−	?	+	−	+
Amiri-Khorasani and Kellis [47]	+	?	−	?	+	+	?
Amiri-Khorasani et al. [48]	+	?	?	?	+	−	+
Amiri-Khorasani et al. [87]	?	?	?	?	+	−	?
Amiri-Khorasani et al. [88]	+	?	−	?	+	−	+
Amiri-Khorasani et al. [89]	+	?	−	?	+	+	+
Amiri-Khorasani et al. [90]	?	−	?	?	+	−	+
Apriantono et al. [23]	?	?	−	?	+	+	+
Beliard et al. [38]	+	?	?	?	+	−	+
Cariolo et al. [91]	?	?	−	?	+	+	+
Currell et al. [18]	+	?	?	?	+	+	+
Deutschmann et al. [92]	−	?	+	?	+	+	+
Draganidis et al. [93]	+	?	−	?	+	+	+
Ferraz et al. [15]	?	?	?	?	+	+	+
Ferraz et al. [94]	+	?	+	?	+	+	+
Ferraz et al. [95]	?	?	?	?	+	+	+
Ferraz et al. [96]	+	?	?	?	+	+	+
Frikha et al. [51]	+	+	?	?	+	+	+
Gaspar et al. [114]	?	?	?	?	+	+	+
Gelen [50]	+	+	?	?	+	+	+
Gharbi et al. [20]	+	?	?	?	+	+	+
Greig [97]	?	?	?	?	+	−	+
Hasan et al. [98]	+	?	?	?	+	+	+
Hasan et al. [99]	+	?	?	?	+	−	+
Izquierdo et al. [116]	−	?	?	?	+	+	?
Juarez et al. [100]	?	?	?	?	+	+	+
Katis et al. [101]	?	?	?	?	+	+	+
Katis et al. [64]	?	?	?	?	+	+	+
Kaviani et al. [117]	+	+	+	?	+	+	?
Kellis et al. [102]	?	?	?	?	+	+	+
Maly et al. [19]	?	?	?	?	+	+	+
Masmoudi et al. [103]	?	?	?	?	+	+	+
McMorris et al. [104]	+	?	?	?	+	−	+
McMorris et al. [105]	+	?	?	?	+	−	+
Muller and Brandes [106]	+	+	+	?	+	+	+
Otten et al. [115]	+	+	+	+	+	+	+
Owen et al. [107]	+	?	?	?	+	+	+
Ozturk and Gelen [108]	+	?	−	?	+	+	?
Pallesen et al. [109]	+	−	?	?	+	−	+
Radman et al. [110]	+	?	?	?	+	+	+
Russell et al. [16]	?	?	?	?	+	+	+
Russell et al. [39]	+	+	+	?	+	+	+
Sánchez-Sánchez et al. [21]	?	?	?	?	+	+	+
Sasadai et al. [111]	+	?	?	?	+	+	?
Stevenson et al. [14]	+	+	+	?	+	+	+
Stone and Oliver [112]	?	?	?	?	+	+	+
Torreblanca-Martinez et al. [13]	?	?	?	?	+	+	+
Zemková and Hamar [114]	?	?	?	?	+	+	+

input argument were also utilized [47, 88, 89]. Accuracy measures were reported in 46% of studies (Table 2). Of these, notational analysis was performed in approximately half (54%) and included factors such as number of goals [86], success percentage [85, 91]; points obtained determined by (1) targets with associated score [18, 110, 114, 117], (2) F-MARC battery of tests [93] and (3) Loughborough soccer shooting test [17, 107, 112]; number of kicks hitting the target [109] and constant/variable error [104, 105]. Manual direct measurement [51], two-dimensional (2D) video kinematic systems [19, 94, 96, 106] or unclear methods [14, 16, 20, 39, 91, 103] enabled calculation of the ball deviation for a given target in 42% of studies. Foot velocity was addressed in 17% of the studies through 3D video kinematic systems (operating at 50 [13] to 500 Hz [23]), taken as the velocity of various segmental locations including the fifth (5^{th}met) [23] or fourth [100] metatarsal head; 5^{th}met base [111]; center-of-mass of markers positioned at the ankle and 5^{th}met head [47]; calcaneus and 5^{th}met head [102]; 5^{th}met head and base [97]; lateral and medial malleolus and 5^{th}met head [98] or the foot segment with lowest *y* axis position value [13]. Other parameters derived from lower limb kinematics–not restricted to foot velocity–in reference to hip, knee and ankle joints (e.g. range-of-motion, linear velocity, angular joint displacement and velocity) were computed in 33% of the selected studies [23, 37, 47–49, 64, 87–90, 98–102, 104, 111].

3.4 Warm-up Methods and Their Influence on Soccer Kicking

3.4.1 Overview

Of a total of ten studies (Table 4), six aimed to verify whether warm-up routines consisting of running plus static or dynamic stretching routines impacted upon subsequent kicking features [37, 47–49, 88, 90]. Two studies combined both aforementioned stretching methods (limited evidence) [50] or included ballistic stretching as an additional condition [51]. Taken together, these eight studies [37, 47–51, 88, 90] indicated greater effectiveness of dynamic/ballistic stretching (in lower limb kinematics [37, 47–49, 90], ball velocity [37, 47, 50, 88] and accuracy [51]) compared to static stretching, which on the other hand tended to impair kicking parameters when applied separately. Standalone studies tested the effects of additional warm-up strategies [50, 105, 108]. Below, results are depicted according to variables, subgroups and level of scientific evidence.

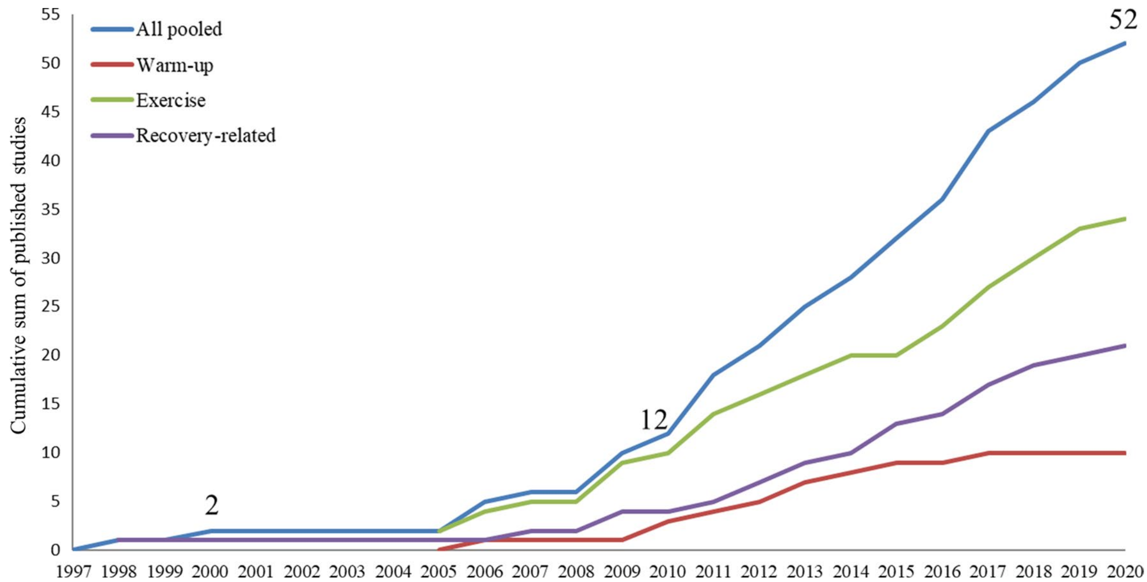

Fig. 4 Cumulative sum showing (per year up to July 2020) the number of published articles that addressed the acute effects of warm-up, exercise and/or recovery-related strategies on soccer kicking ability

3.4.2 Stretching Routines

In senior players, a moderate evidence for greater ball velocity following dynamic stretching compared to static stretching (SMD = 0.99–2.44) [37, 47, 88] was observed. When participants of these studies were divided according to playing standard, there was also a moderate evidence of greater ball velocity after dynamic versus static stretching in sub-elite (SMD = 0.99–2.44) [47, 88] and in elite players (SMD = 2.40) [37]. Similarly, moderate evidence of the benefits of dynamic stretching as compared to a static stretching routine (SMD = 0.75) was found regarding kicking accuracy in sub-elite youth players [51]. Limited evidence existed showing a positive influence of dynamic stretching effects on foot velocity (i.e. in sub-elite senior players; SMD = 1.00) [47].

3.4.3 Additional Methods

Three studies in senior soccer players provided limited evidence on the effects of additional distinct warm-up routines other than only running plus stretching protocols. Warm-ups consisting of running followed by the execution of unloaded squat, kicking movement simulation with elastic band or whole-body vibration increased ball velocity more than running alone in sub-elite players (MD = 4.84–6.03%) [108]. In elite players, running plus dynamic warm-up movements (e.g. straight leg kick, skipping, high knee) [50] produced improvements in ball velocity compared to solely a running warm-up (SMD = 1.21). Finally, accuracy (SMD = 0.03–0.78) or ankle velocity of the kick (SMD = 0.59–1.07) did not significantly differ after a warm-up on a cycle ergometer, ball juggling/kicking against a wall or a combination of these two methods in sub-elite players [105].

3.5 Exercise-Induced Effects on Soccer Kicking

3.5.1 Overview

Given the variety of exercise protocols reported in the included studies (Table 5), these were classified primarily according to the fatigue intended to elicit (local or general) [118], degree of load (submaximal fixed-intensity, graded until exhaustion, intermittent or all-out) [119, 120] and duration (explosive, high-intensity or endurance) [119, 121]. As such, the majority of the physical exercises found (56%) were designed as general intermittent endurance exercise protocols [14–19, 38, 39, 85, 86, 94, 96, 97, 102, 107, 112–114, 116]. There were also groups of studies examining the impact of general intermittent high-intensity exercise [20, 21, 103], general graded until exhaustion endurance exercise [64, 101, 110], local all-out high-intensity exercise [13, 87, 89] and local submaximal fixed-intensity endurance exercise [23, 93]. These latter protocols (except general graded until exhaustion endurance) provided only limited evidence of their effects on kicking kinematics or performance. Single studies (also providing limited evidence) verified the effects linked to general all-out endurance exercise [95], general submaximal fixed-intensity endurance exercise [100], local graded until exhaustion endurance exercise [104] and a soccer practice session [91]. Collectively,

Table 2 Demographic characteristics, location of the experiment, apparatus for data collection, and instructions given to the participants in studies included in the review

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
Abbey and Rankin [85]	12	22.5	1st div NCAA	–	Laboratory (artificial grass)	–	–	ACCUR–Notational analysis	Attempting to hit a goal
Abt et al. [86]	6	18	Recreational	Midfielders	–	–	–	ACCUR–Notational analysis	Shoot at a target goal
Ali et al. [17]	16	21.3	Semi-PRO	Outfield (various)	Laboratory	–	–	ACCUR–Notational analysis V_{BALL}–Radar–The SpeedCheck sports, UK	Shoot across the goalkeeper towards the open space of the goal
Amiri-Khorasani et al. [87]	5	25.6	Experienced	–	Laboratory	Yes	5 (435 g, 0.69 atm)	$KINEMATICS_{LIMB}$–Video 3D–Vicon MX-F20, UK (200 Hz)	Strike the ball as hard as possible
Amiri-Khorasani and Kellis [47]	12	19.2	Collegiate	–	Laboratory	Yes	5 (435 g, 0.69 atm)	$KINEMATICS_{LIMB}$ and V_{FOOT}–Video 3D–Vicon MX-F20, UK (200 Hz) V_{BALL}–estimated using V_{FOOT}	Kick as hard as possible
Amiri-Khorasani et al. [88]	6	19.2	Collegiate	–	–	Yes	5 (435 g, 0.69)	$KINEMATICS_{LIMB}$–Video–Vicon MX-F20, UK (200 Hz) V_{BALL}–estimated using V_{FOOT}	Maximal velocity place kick
Amiri-Khorasani et al. [89]	5	25.6	Experienced		Laboratory	Yes	5	$KINEMATICS_{LIMB}$–Video 3D–Vicon MX-F20, UK (200 Hz) V_{BALL}–estimated using V_{FOOT}	Hit the ball as hard as possible
Amiri-Khorasani et al. [48]	18	19.2	PRO	–	–	Yes	5 (435 g, 0.69 atm)	$KINEMATICS_{LIMB}$–Video 3D–manual digitisation–Vicon Motion Systems, USA (50 Hz)	Maximal velocity place kick

Table 2 (continued)

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
Amiri-Khorasani [49]	15	21.2	PRO	–	–	Yes	5 (435 g, 0.69 atm)	KINEMATIC-S_{LIMB}–Video 3D–Eagle Motion Analysis Corp., USA (200 Hz)	Kick the ball as hard as possible
Amiri-Khorasani and Ferdinands [37]	24	19.4	PRO	–	–	–	(435 g, 0.69 atm)	$KINEMATICS_{LIMB}$ and V_{BALL}–Video 3D–manual digitisation–Peak Performance, USA (50 Hz)	Maximal velocity kick
Amiri-Khorasani et al. [90]	18	19.2	PRO	–	–	Yes	5 (435 g, 0.69 atm)	KINEMATIC-S_{LIMB}–Video 3D–manual digitisation–Peak Performance, USA (50 Hz)	Maximal velocity place kick
Apriantono et al. [23]	7	20	Univ	–	–	Yes	5 (435 g, 0.69 atm)	$KINEMATICS_{LIMB}$, V_{FOOT} and V_{BALL}–Video 3D–manual digitisation–DKH Inc., Japan (500 Hz)	Maximal kick toward a goal
Beliard et al. [38]	22	13.5	Highly trained	Defenders/midfielders	Pitch (artificial grass)	–	–	V_{BALL}–Radar–Stalker ATSII Applied concept, USA	To target the radar behind the net
Cariolo et al. [91]	12	21.1	Semi-PRO	–	–	–	–	ACCUR–Video 2D–Kinovea, France	Kick the ball to score
Currell et al. [18]	11	21.4	≥Recreational	–	Pitch (artificial grass)	–	–	ACCUR–Notational analysis	–
Deutschmann et al. [92]	40	23.1	Regional	All pooled	Court	–	–	V_{BALL}–Radar–SpeedTrac Speed Sport, USA	Kick performed at maximum power
Draganidis et al. [93]	10	20	Elite	–	Pitch (natural grass)	–	–	ACCUR–Notational analysis	Shot into the goal by aiming at different segments

Table 2 (continued)

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
Ferraz et al. [94]	12	19.7	Semi-PRO	–	–	–	70 Ø (430 g)	V_{BALL}–Radar–Sports Eletronics Inc., USA ACCUR–Video 2D	Kick with maximum force and attempt to hit a target
Ferraz et al. [15]	10	27.3	Amateur	–	–	–	70 Ø (430 g)	V_{BALL}–Radar–Sports Eletronics Inc., USA	Kick with maximum force and attempt to hit a target
Ferraz et al. [95]	9	19 – 35	Experienced	–	–	–	68–70 Ø (410–50 g)	V_{BALL}–Radar–Sports Eletronics Inc., USA	Shoot as hard as possible
Ferraz et al. [96]	24	19.7	Semi-PRO	–	–	–	70 Ø (430 g)	V_{BALL}–Radar – Applied Concepts Inc., USA ACCUR–Video 2D	Kick with maximum force and attempt to hit a target
Frikha et al. [51]	20	13.4	Regional	–	Court	Yes	5 (430 g, 0.79 atm)	ACCUR–Manual direct measurement	Kick to a target
Gaspar et al. [114]	20	13.8	Regional	All pooled	Pitch (artificial grass)	–	5	ACCUR–notational analysis V_{BALL}–Radar–Stalker Sports, USA (34.2–35.2 GHz)	1-Maximal effort kick 2-Kick into a goal that was divided into zones, to achieve as high a score as possible
Gelen [50]	26	23.3	3rd div PRO	–	–	–	–	V_{BALL}–Radar–Sports Radar, Astro Products, USA	Maximal speed shoot by targeting the middle of the goal without requiring a hit
Gharbi et al. [20]	10	14.6	–	–	Pitch (artificial grass)	–	–	ACCUR–Video	–
Greig [97]	10	20.8	PRO	–	–	–	–	V_{FOOT}–Video 3D–Qualisys, Sweden (200 Hz)	Maximal velocity kick with no accuracy constraint
Hasan et al. [99]	12	15.7	Local recreational	–	–	Yes	5	KINEMATIC-S_{LIMB}–Video 3D–C-Motion, USA (200 Hz) and 2D–Kinovea, France	Kick as hard as possible

Table 2 (continued)

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
Hasan et al. [98]	12	15.4	Local recreational	–	Laboratory (synthetic surface)	Yes	5	KINEMATICS-$_{LIMB}$, V_{FOOT} and V_{BALL}–Video 3D–C-Motion, USA (200 Hz)	Kick to generating maximum velocity
Izquierdo et al. [116]	174	17.6	National	All (separate)	Pitch (natural grass)	–	–	V_{BALL}–Radar–Stalker Professional Radar, USA	Maximal ball velocity when aiming at goal
Juarez et al. [100]	21	16.1	1st div National junior	–	Laboratory	Yes	–	KINEMATICS$_{LIMB}$, V_{FOOT} and V_{BALL}–Video 3D–VICON Motion Systems, UK (250 Hz)	Maximal kick
Katis et al. [64]	10	26.3	Amateur	–	Laboratory	–	–	KINEMATICS$_{LIMB}$ and V_{BALL}–Video 3D–Vicon motion analysis systems, UK (120 Hz)	Kick the ball as fast and hard as possible aiming at the centre of the goalpost
Katis et al. [101]	10	24.5	Amateur	–	Laboratory	Yes	5 (430 g, 0.88 atm)	KINEMATICS$_{LIMB}$ and V_{BALL}–Video 3D–Vicon motion analysis systems, UK (120 Hz)	Kick the ball as fast and hard as possible aiming at the centre of the goalpost
Kaviani et al. [117]	8	30	Recreational	–	Laboratory	–	–	ACCUR–Notational analysis	–
Kellis et al. [102]	10	22.6	Amateur	–	–	–	–	KINEMATICS$_{LIMB}$, V_{FOOT} and V_{BALL}–Video 3D–Kwon 3-D Visol Inc., Korea (120 Hz)	Kick as powerful as the participants could
Maly et al. [19]	20	22.4	Elite PRO	Goalkeeper excluded	Pitch (artificial grass)	Yes	5	ACCUR–Video 2D–TEMA Biomechanica 2.3, Australia (50 Hz) V_{BALL}–Radar–Stalker Plano, USA (33.4–36 GHz)	Kick to the centre of the goal with maximum effort
Masmoudi et al. [103]	10	14.6	–	–	Pitch (artificial grass)	–	–	–	–

Table 2 (continued)

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
McMorris et al. [104]	12	20	Collegiate	–	–	–	– (0.41–0.48 atm)	ACCUR–Notational analysis	Aim for the center of the target
McMorris et al. [105]	12	21	Recreational	–	–	–	55 Ø	ACCUR–Notational analysis $KINEMATICS_{LIMB}$–Video 2D–Peak Motus Software 32 version 2000 (100 Hz)	Kick as hard as possible at a target
Muller and Brandes [106]	26	23.9	Amateur	–	Indoor	–	–	V_{BALL}–Radar–SpeedTrac XTM, USA ACCUR–Video 2D–VirtualDub, Avery Lee	Objective to strike the target with maximum velocity
Otten et al. [115]	34	25	Amateur	–	Pitch	Yes	5	V_{BALL}–Radar–WG 54, D&L, The Netherlands	Maximal effort shots
Owen et al. [107]	13	22.2	Semi-PRO	–	Indoor	–	–	ACCUR–Notational analysis V_{BALL}–Radar–SpeedCheck, UK	Shoot the ball at targets in a full-sized goal
Ozturk and Gelen [108]	21	19.7	Amateur	–	–	–	–	V_{BALL}–Radar–Sports Radar 3600, Astro Products, USA	Kick at a maximal speed and aim at a plastic figure
Pallesen et al. [109]	19	16.5	Local	–	Indoor pitch	–	–	ACCUR–Notational analysis	Kick the ball to a target
Radman et al. [110]	28	22.9	Semi-PRO	–	Pitch (artificial grass)	Yes	5	ACCUR–Notational analysis/Video V_{BALL}–Radar–Applied Concept Marketing, USA	Accurately hit the most distant scoring zones of the leg-opposite side of the goal while keeping realistic (match-specific) kicking velocity
Russell et al. [39]	15	18	Academy PRO	–	Indoor (rubberized surface)	–	–	ACCUR–Video–Vicon, USA V_{BALL}–Video–Quintic, UK	Kick the ball as accurately as possible at the target

Table 2 (continued)

Study	Participants				Location (surface)	Ball		Technology and key variables	Instruction/aim
	n	Age (mean)	Level	Position		FIFA-approved	Size (Mass and pressure)		
Russell et al. [16]	15	18.1	Academy PRO	–	Indoor (synthetic track)	Yes	5	ACCUR–Video–Sony Ltd, UK (50 Hz) V_{BALL}–Video–Quintic Consultancy Ltd, UK (50 Hz)	Kick the ball toward one of shooting targets
Sánchez-Sánchez et al. [21]	18	22.4	Amateur	Outfield excluding goalkeeper	Pitch (artificial grass)	Yes	–	V_{BALL}–Radar–Radar Sales, USA	Kick at the fastest speed possible
Sasadai et al. [111]	11	20.8	Experienced	–	–	Yes	5 (430 g, 0.87 atm)	$KINEMATICS_{LIMB}$, V_{FOOT} and V_{BALL}–Video 3D–DIPP-Motion XD, Japan (200 Hz)	Maximal kick
Stevenson et al. [14]	22	20	Univ	–	Indoor	–	5	ACCUR and V_{BALL}–Video–Kinovea Org., France (50 Hz)	Kick toward one of four randomly illuminating targets
Stone and Oliver [112]	9	20.7	Semi-PRO	Outfield (various)	Pitch (artificial grass)	–	–	ACCUR–Notational analysis	–
Torreblanca-Martinez et al. [13]	15	U18	Top	–	–	–	–	V_{FOOT}–Video 3D–CLIMA system/3D Soccer Analyzer STT®, Spain (50 Hz)	Maximal kick
Zemková and Hamar [113]	10	21.8	Elite	–	–	–	–	V_{BALL}–Analogic velocity sensor–FiTRO Dyne Premium, Slovakia (100 Hz)	Kick as fast as possible

PRO professional, *Univ* university, *div* division, *Video* videogrammetry, V_{BALL} ball velocity, V_{FOOT} foot velocity, *ACCUR* accuracy; *n* number of participants, – information not reported or unclear

Table 3 Task constraints adopted in each study included in the review

Study	Trials		Kick type			Approach run	Target			Goal size (m)	Opponent
	Number	Interval (s)	Limb	Foot region	Ball condition		Location	Distance (m)	Dimensions (m)		
Abbey and Rankin [85]	5×8	6	–	–	Rolling	7,6 m	Entire goal	13.7	–	1.8×1.2	–
Abt et al. [86]	4×8	–	Dominant	Inside	–	–	Entire goal	15.6	–	1.5–width	–
Ali et al. [17]	3×10	60	Both	–	Rolling	–	Various–entire goal	~16.5 to 25	1.2×0.8–upper corners	2.44×7.32	Yes (GK)
Amiri-Khorasani et al. [87]	10	–	Dominant	Instep	Stationary	3 m, 0°	–	3	1×1	–	–
Amiri-Khorasani and Kellis [47]	2×2×5	–	Dominant	Instep	–	3 m, 0°	–	3	1×1	–	–
Amiri-Khorasani et al. [88]	2×2×5	–	Dominant	Instep	Stationary	3 m, 0°	–	3	1×1	–	–
Amiri-Khorasani et al. [89]	10	–	–	Instep	Stationary	3 m, 0°	–	3	1×1	–	–
Amiri-Khorasani et al. [48]	3×5	–	Dominant	Instep	Stationary	3 m, 0°	Goal centre	11	2×2	–	–
Amiri-Khorasani [49]	3×5	–	Dominant	Instep	Stationary	3 m, 0°	–	3	1×1	–	–
Amiri-Khorasani and Ferdinands [37]	3×5	–	Dominant	Instep	Stationary	3 m, 0°	Goal centre	11	2×2	–	–
Amiri-Khorasani et al. [90]	3×5	None	Dominant	Instep	Stationary	3 m, 0°	Goal centre	11	2×2	–	–
Apriantono et al. [23]	2×5	–	–	Instep	–	–	Goal centre	11	–	3×2	–
Beliard et al. [38]	2×8×2	–	–	–	–	–	–	10	–	–	No
Cariolo et al. [91]	2×8	–	–	–	–	–	Lower/upper corners	–	–	–	–
Currell et al. [18]	3×6×10	None	Dominant	–	Stationary	–	Various–entire goal	16.46	–	–	–
Deutschmann et al. [92]	2×3	–	Dominant	Instep	–	3 m	–	–	–	–	–
Draganidis et al. [93]	3×5×6	–	–	–	Stationary	–	Various–entire goal	16	–	–	–
Ferraz et al. [94]	7×3	–	–	Instep	–	–	Goal centre	11	1×1– circle	7.32×2.44	–
Ferraz et al. [15]	6×3	–	–	Instep	–	–	Goal centre	7	1×1– circle	3×2	–
Ferraz et al. [95]	2×2	None	–	Instep	–	–	–	11	–	–	–
Ferraz et al. [96]	6×3	–	–	Instep	–	–	Goal centre	11	1×1– circle	7.32×2.44	–

Table 3 (continued)

Study	Trials		Kick type			Approach run	Target			Goal size (m)	Opponent
	Number	Interval (s)	Limb	Foot region	Ball condition		Location	Distance (m)	Dimensions (m)		
Frikha et al. [51]	4×2×10	SS 15[a]	Dominant	Inner	Stationary	SS angle and distance	Entire goal	6.10	–	2.435×2.44	–
Gaspar et al. [114]	6×3	60	Dominant	–	Stationary Rolling	5 m	–	11	–	7.32×2.44	–
	6×12	–	Dominant	–		5 m	Various–entire goal	–	0.7×0.7–upper corners	–	No
Gelen [50]	4×3	–	–	–	–	–	Goal centre	11	–	–	–
Gharbi et al. [20]	2×2×10	–	–	–	–	–	Entire goal	6.1	–	2.435×1.22	–
Greig [97]	8×1	–	–	–	Stationary	SS	–	–	–	–	–
Hasan et al. [98]	4×5	–	–	Instep	Stationary	–	–	6.1	–	–	No
Hasan et al. [99]	20	–	–	Instep	Stationary	–	–	6.1	–	3×2	No
Izquierdo et al. [116]	3	60	–	Instep	–	2 steps	–	5	–	–	–
Juarez et al. [100]	3	30	Dominant	Instep	–	4–5 m	–	5	–	–	–
Katis et al. [64]	2×3	30	–	Instep	Stationary	45º, 1 step	Goal centre	7	–	–	–
Katis et al. [101]	2×2	15	Both	Instep	Stationary	45º, 1 step	Goal centre	7	–	–	–
Kaviani et al. [117]	–	–	–	–	Stationary	–	Various–entire goal	16.46	–	–	–
Kellis et al. [102]	3×3	30	–	Instep	–	2 steps	Entire goal	11	–	2.5×7.5	–
Maly et al. [19]	2×3	–	Dominant	–	–	–	Goal centre	–	–	–	–
Masmoudi et al. [103]	3×2×10	–	–	–	–	–	–	6.1	–	–	–
McMorris et al. [104]	3×3	–	–	–	–	1 m	Various–entire goal	7	Width 0.3–goal centre	0.24×3.3	–
McMorris et al. [105]	2×4×9	–	–	–	–	–	Various–entire goal	8.5	Width 0.075–goal centre	0.24×3.3	–
Muller and Brandes [106]	2×7	–	–	–	–	0º, 2 m	Goal centre	8	0.3×0.3	3×2	–
Otten et al. [115]	3×3	30	Dominant	–	–	SS	–	5	–	–	–
Owen et al. [107]	3×2×10	60	Both	–	Rolling	–	Various–entire goal	~16.5	1.2×0.8–upper corners	–	Yes (GK)
Ozturk and Gelen [108]	4×3	–	–	–	–	–	Goal centre	11	–	–	–
Pallesen et al. [109]	2×3 x SS	60[a]	–	–	Stationary and rolling	–	Entire goal	5	–	1×1	–
Radman et al. [110]	2×6×10	6	Dominant	–	Stationary	2 steps	Various–entire goal	16.5	0.488×0.488–upper corners	3×2	–

Table 3 (continued)

Study	Trials		Kick type			Approach run	Target			Goal size (m)	Opponent
	Number	Interval (s)	Limb	Foot region	Ball condition		Location	Distance (m)	Dimensions (m)		
Russell et al. [39]	4×8	30	–	–	Rolling	–	Lower/upper corners	15	1×0.5	7.33×2.44	–
Russell et al. [16]	4×4	–	SS	–	Rolling	–	Lower/upper corners	15	1×0.5	7.33×2.44	–
Sánchez-Sánchez et al. [21]	4×2×2	60	–	–	Stationary	–	–	11	–	–	–
Sasadai et al. [111]	4×5	–	–	Instep	–	–	–	–	–	–	–
Stevenson et al. [14]	3×5×4	–	Dominant	–	Rolling	–	Lower/upper corners	–	–	7.33×2.44	–
Stone and Oliver [112]	2×10	30	Both	–	Rolling	–	Various–entire goal	~16.5	1.2×0.8–upper corners	2.44×7.32	–
Torreblanca-Martinez et al. [13]	3×1	–	–	Instep	–	–	–	–	–	–	–
Zemková and Hamar [113]	3×3	–	Dominant	–	–	–	–	–	–	–	–

When the number of trials was expressed by two numbers, these are in reference to series/time moment/experimental conditions × number of trials performed; when the number of trials was expressed by three numbers, these are in reference to experimental conditions × time moment × number of trials performed

SS self-selected, *GK* goalkeeper, – information not reported or unclear

[a]Total time to complete the required number of trials

Table 4 Effects of warm-up methods on soccer kicking performance reported in studies included in the review

Study (*N* = 10)	Design	Warm-up method (WU)	Transition		Main results			
			Min	Type	Foot velocity	Ball velocity	Accuracy	Additional kinematics
Stretching routines								
Amiri-Khorasani and Kellis [47]	Pre-post Randomized Balanced	WU_1: 4′ jog + 5 kicks + 30″ rep ss WU_2: 4′ jog + 5 kicks + 5 × 1″ rep × 3 vel (slow, moderate, max) ds	2	Rest	Post-WU_2 vs. pre-WU_2 SMD = 1.00 [0.14; 1.86] MD = 11.52%	$\Delta WU_1 < \Delta WU_2$ SMD ≥ − 0.99 MD = − 17.33%		$\Delta WU_1 < \Delta WU_2$ Knee and ankle max ang vel SMD ≥ − 0.96 MD = − 13.41 to − 11.1%
Amiri-Khorasani et al. [88]	Pre-post Randomized Balanced	WU_1: 4′ jog + 5 kicks + ss WU_2: 4′ jog + 5 kicks + ds	2	Rest		$\Delta WU_1 < \Delta WU_2$ SMD = − 2.44 [0.80; 4.09] MD = − 132.67%		
Amiri-Khorasani et al. [48]	Post-only Counterbalanced Randomized RM	WU_1: 4′ jog + no stretching WU_2: 4′ jog + ss WU_3: 4′ jog + ds	2	Rest				Post-WU_2 < post-WU_3 Ang disp max knee flex and ang vel knee SMD = − 2.40 to − 0.95 MD = − 176.40%
Amiri-Khorasani and Ferdinands [37]	Post-only Randomized Balanced RM	WU_1: 4′ jog + no stretching WU_2: 4′ jog + ss WU_3: 4′ jog + ds	2	Rest		$WU_1 > WU_2$ SMD = − 0.48 [− 1.05; 0.09] MD = 4.62% $WU_2 < WU_3$ SMD = 2.40 [1.65; 3.16] MD = − 24.87% $WU_1 < WU_3$ SMD = 2.05 [1.34; 2.76] MD = − 19.10%		Hip and knee ang vel $WU_3 > WU_1 > WU_2$ SMD = 0.61–1.90 MD = 17.11–147.88%
Amiri-Khorasani [49]	Post-only Balanced RM	WU_1: 4′ jog + no stretching WU_2: 4′ jog + ss WU_3: 4′ jog + ds	2	Rest				$\Delta WU_2 < \Delta WU_3$ Hip, knee and ankle DROM SMD = 0.25–0.80 MD = 103.04–228.89%
Amiri-Khorasani et al. [90]	Post-only RM	WU_1: 4′ jog + no stretching WU_2: 4′ jog + 4′ ss WU_3: 4′ jog + 4′ ds	2	Rest				Hip DROM Post-WU_2 < post-WU_3 SMD = 1.12 [0.41; 1.82] MD = 601.80%
Frikha et al. [51]	Post-only Randomized Partially balanced	WU_1: 5′ jog 70% MAS + 10′ resting WU_2: 5′ jog 70% MAS + 10′ ss + 6 VJ WU_3: 5′ jog 70% MAS + 10′ ds + 6 VJ WU_4: 5′ jog 70% MAS + 10′ bs + 6 VJ	1	Rest			$WU_1 < WU_3$ SMD = − 0.53 [− 0.10; 1.17] MD = − 10.33% $WU_2 < WU_3$ SMD = − 0.58 [− 1.22; 0.05] MD = − 13.79% $WU_2 < WU_4$ SMD = − 0.75 [0.10; 1.39] MD = − 11.59%	

Table 4 (continued)

Study (N = 10)	Design	Warm-up method (WU)	Transition		Main results			
			Min	Type	Foot velocity	Ball velocity	Accuracy	Additional kinematics
Additional methods								
Gelen [50]	Post-only Randomized Balanced RM	WU_1: 5′ jog + 2′ walking + 5′ jog 140 bpm WU_2: 5′ jog + 2′ walking + 5′ jog 140 bpm + 10′ ss WU_3: 5′ jog + 2′ walking + 5′ jog 140 bpm + 10′ de WU_4: 5′ jog + 2′ walking + WU_2 + WU_3	4–5	Seated		$WU_3 > WU_1$ SMD = 1.21 [0.62; 1.81] MD = 3.25% $WU_2 < WU_1$ SMD = − 0.72 [− 1.28; − 0.16] MD = − 2.16%		
McMorris et al. [105]	Post-only Randomized RM	WU_1: 12′ sitting WU_2: 15′ cycling (3′ 60 rpm/50 W + 12′ T_{LA}) WU_3: 12′ ball juggling + wall volley test WU_4: 6′ WU_3 + 6′ cycling at T_{LA}	20 s	–			$WU_1 = WU_{2–4}$ SMD = 0.03–0.78 MD = − 24.43 to 55.17%	Vertical ankle vel WU_4 vs. $WU_{2,3}$ SMD = 0.89–1.07 MD = − 26.92 to − 27.62%
Ozturk and Gelen [108]	Post-only Randomized Balanced RM	WU_1: 10′ jog 140 bpm + 2′ walking WU_2: WU_1 + 3 × 10 rep unloaded squat WU_3: WU_1 + 3 × 10 rep kick with elastic band WU_4: WU_1 + 6 × 30″ whole-body vibration (30 Hz)	3–4	Seated		$WU_1 < WU_{2–4}$ P = 0.01 MD = − 4.84 to − 6.03%		

SMD standardised mean difference [upper; lower confidence limits or range], *MD* mean percentage difference, *vel* velocity, *rep* repetitions, *jog* jogging, *ss* static stretching, *ds* dynamic stretching, *bs* ballistic stretching, *de* dynamic exercises, *max* maximal, *ang* angular, *VJ* vertical jump, *bpm* beats per minute, *RM* repeated measures, *TLA* lactate threshold, *disp* displacement, *DROM* dynamic range-of-motion, *MAS* maximal aerobic speed estimated using the Yo-Yo intermittent recovery test Level 1 [117]

physical exercise negatively impacted upon ball velocity in 65% of the studies. In contrast, accuracy remained stable across exercise protocols in 74% of studies. No reports showed a significant increase, post-exercise, in any kicking performance variables. The following section includes descriptions of exercise-induced effects according to the level of evidence provided per variable of kicking and within subgroups.

3.5.2 General Intermittent Endurance Exercise

In accordance with findings from a previous review [12], exercise protocols requiring general intermittent endurance efforts were also sub grouped according to format: 11 vs. 11 soccer match-play [113, 114, 116], simulated soccer demands with [14–16, 39, 94, 96] or without [17–19, 38, 85, 102, 107, 112] ball skills or laboratory-based protocols (limited evidence) [86, 97].

3.5.2.1 Simulated soccer demands with ball skills Conflicting evidence existed regarding the effects on ball velocity of simulated soccer demands interspersed with execution of ball skills in senior players, when all playing standards were pooled (SMD = 0.19–1.50) [14–16, 39, 96]. Sub-elite senior players exhibited moderate evidence pointing to no significant changes (SMD = 0.19–0.45) [14, 15, 96], while evidence was conflicting in elite senior peers (SMD = 0.45–1.50) [16, 39]. Irrespective of playing standard, strong evidence [14, 16, 39, 94, 96] indicated kick accuracy was not modified following simula-

Table 5 Exercise-induced effects on soccer kicking performance reported in studies included in the review

Study ($N = 34$)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
General intermittent endurance EX							
Simulated soccer demands (no ball skills)							
Abbey and Rankin [85]	Mid-post	5 × 3 rep 15′ (jog 55% VO_{2max} + running at 120% VO_{2max} + walking + jog at 55% VO_{2max} + sprint max)	10			Mid = post SMD = 0.58–2.94 MD = 3.10–16.26%	
Ali et al. [17]	Pre-post	6 × 15′ × 10–12 rep (walking + running at 95% VO_{2max} + jog at 55% VO_{2max} + sprint + 3′ resting)—LIST [122]	–		Pre = post SMD = − 0.02 [− 0.71; 0.68] MD = 0.14%	Pre > post SMD = − 0.30 [− 0.99; 0.40] MD = 12.62%	
Beliard et al. [38]	Pre-mid-post	2 × 36′ (3 bouts × 12′) locomotor exercise (including standing, walking, jogging, running, sprinting)—SAFT[90] [123]	15		Pre > post SMD = − 0.47 [− 1.07; 0.13] MD = 3.51%		
Currell et al. [18]	Pre-mid-post	10 × 6′ [4 rep 90″: 10″ walking + 2 × (10″ jog at 50% max vel + 10″ at 95% max vel) + 15″ walking + 5″ sprint + 15″ jog at 50% max vel + 5″ sprint]	10			Pre > post $P < 0.001$ MD = 12.4%	
Kellis et al. [102]	Pre-mid-post	9600 m [4 × 12 × 200 m: 60 m walking + 15 m sprint (5 m dacc + 5 m walking) + 60 m jog + 60 m running]	15	Pre > post SMD = − 1.03 [− 1.98; − 0.09] MD = 14.11%	Pre > post SMD = − 1.37 [− 2.37; − 0.38] MD = 16%		Pre > post Ankle ang, shank max ang vel SMD = − 0.38 to − 0.88 MD = − 8.81 to − 10.76%
Maly et al. [19]	Pre-post	4 bouts at 10–13 km/h (0–160 m) + 7 at 13.5–14 km/h (160–440 m) + 0.5 km/h increments per 8 bouts, with 10 s active recovery between bouts—Yo-Yo IRT1 [124]	–		Pre > post SMD = − 1.03 [− 1.70; − 0.37] MD = 5.82%	Pre = post SMD = − 0.19 [− 0.81; 0.44] MD = − 10%	

Table 5 (continued)

Study ($N = 34$)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Owen et al. [107]	Pre-post	6 blocks × 15′ × 11 rep (20 m walking, sprint, running at 95% VO_{2max} + jog at 55% VO_{2max}), with 3′ interval between blocks—LIST [122]	–		Pre > post SMD = − 0.50 to − 0.73 MD = − 2.92 to − 4.64%	Pre = post SMD = − 0.27 [− 1.04; 0.51] MD = 14.29%	
Stone and Oliver [112]	Pre-post	3 × 15′: 10 × 90″ [3 × 20 m walking at 5 km/h + 1 × 15 m at max vel (+ 5 m dacc) + 3 × 20 m at 9 km/h + 2 × 20 m at 14 km/h] + 3′ rec—LIST [122]	–			Pre > post SMD = − 0.88 to − 1.42 MD = − 25.36 to − 36.11%	
Simulated soccer demands (including ball skills)							
Ferraz et al. [15]	Pre-mid-post	5 × 90″ exercises (~ 168 m including jumping, skipping, multiple COD, dribble, passing, jog and 90″ resting)	–		Pre = post SMD = − 0.19 to − 0.44 MD = − 4.58 to − 10.23%		
Ferraz et al. [94]	Post-only Randomized RM	EX: Exercise circuit (~ 177 m) including jumping, skipping, multiple fast COD, ball conduction, passing, explosive sprints and low-speed running EX_1: 15′ warm-up (jog + kick exercises) EX_2: EX performed slowly and comfortably EX_3: EX performed a bit slower than EX_4 EX_4: EX performed at preferred tempo EX_5: EX performed a bit faster than EX_4 EX_6: EX performed as fast as possible	–		Post-EX_1 = $EX_{2–6}$ SMD = − 0.01 to − 0.69 MD = − 0.04 to − 4.55%	Post-EX_1 = $EX_{2–6}$ SMD = 0.05–0.3 MD = 2.65–13.76%	

Table 5 (continued)

Study ($N=34$)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Ferraz et al. [96]	Pre-mid-post Randomized RM	5×90″ exercises (~168 m including jumping, skipping, multiple COD, dribble, passing, jog and 90″ resting)	–		Pre = post SMD = −0.37 [−0.94; 0.20] MD = 2.06%	Pre = post SMD = 0.44 [−0.13; 1.01] MD = 15.21%	
Russell et al. [39]	Pre-mid-post	2×45′ (7 rep×4.5′ exercise, 3 repeated cycles: 3×20 m walking, 1×side walking, 1×15 m sprint or 20 m dribble + 4″ rec + 5×20 m jog at 40% VO_{2max} + 20 m backward jog at 40% VO_{2max} + 2 steps×20 m at 85% VO_{2max} + 2′ passing + 1′ rec)—SMS [125]	15		Pre > post SMD = −1.50 [−2.33; −0.68] MD = 10.25%	Pre = post SMD = −0.10 [−0.81; 0.62] MD = −5.82%	
Russell et al. [16]	Pre-mid-post	2×45′ (7 rep×4.5′ exercise, 3 repeated cycles: 3×20 m walking, 1×side walking, 1×15 m sprint or 20 m dribble + 4″ rec + 5×20 m jog at 40% VO_{2max} + 20 m backward jog at 40% VO_{2max} + 2 steps×20 m at 85% VO_{2max} + 2′ passing + 1′ rec)—SMS [125]	15		Pre = post SMD = 0.45 [−0.28; 1.17] MD = 4.67%	Pre vs. post SMD = −0.53 [−1.26; 0.20] MD = −25.95%	
Stevenson et al. [14]	Pre-mid-post	2×45′ + 2×15′: adapted version of the SMS [125] including extra-time	15		Pre = post SMD = −0.45 [−1.05; 0.15] MD = 5.88%	Pre = post SMD = 0.07 [−0.52; 0.66] MD = 3.23%	
Laboratory-based protocols							
Abt et al. [86]	Pre-post	60′ treadmill running (reps 5′ at 12 km/h and 2.5° + 30″ at 12 km/h and 7° + 75″ at 4 km/h and 0° inclination)	–			Pre = post SMD = −0.38 [−1.53; 0.77] MD = 3.44%	

Table 5 (continued)

Study ($N = 34$)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Greig [97]	Pre-mid-post	6 × 15′ intermittent treadmill running simulating match-play bouts (stationary, walking, jogging, cruising and sprinting) [126]	15	Pre = post SMD = − 0.20 [− 1.08; 0.68] MD = − 1.07%			Pre = mid = post Thigh and shank ang disp SMD = − 0.16 to 1.56 MD = − 22.82 to 21.75%
11 vs. 11 soccer match-play demands							
Gaspar et al. [114]	Pre-post	35′ simulated soccer match	–		Pre vs. post SMD = − 0.12 [− 0.74; 0.50] MD = 1.78%	Pre vs. post SMD = − 0.04 [− 0.66; 0.58] MD = 2.18%	
Izquierdo et al. [116]	Pre-mid-post RM	2 × 45′ soccer competition match-play	15		Pre > post SMD = − 0.57 to − 1.04 MD = − 2.91 to − 6.51%		
Zemková and Hamar [113]	Pre-mid-post	2 × 45′ soccer match-play	15–20		Pre = post SMD = − 0.39 to − 0.55 MD = − 2.55 to − 3.69%		
General intermittent high-intensity EX							
Gharbi et al. [20]	Pre-post Randomized RM	EX_1: 10 × 20 m max running with 20″ passive recovery EX_2: 10 × 20 m max running with 20″ active recovery (juggling exercises without using upper limbs)				Pre = post SMD = 0.09–0.13 MD = 1.91–2.65%	
Masmoudi et al. [103]	Pre-post	10 × 20 m max slalom running with the ball, with 90″ rec between efforts	–			Pre = post SMD = − 0.92 to 0.35 MD = − 14.46 to 7.29%	
Sánchez-Sánchez et al. [21]	Pre-post	6 × 40 m (20 + 20 m) sprints with 20″ active recovery	–		Pre > post SMD = − 1.06 [− 1.77; − 0.36] MD = 9.45%		
General graded until exhaustion endurance EX							

Table 5 (continued)

Study (N = 34)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Katis et al. [64]	Pre-post	Treadmill running until exhaustion (2′ at 10 km/h + 2′ at 12 km/h + increments of 2° inclination per 1′ until 12%)	–		Pre > post SMD = − 0.85 [− 1.77; 0.08] MD = 8.15%		
Katis et al. [101]	Pre-post	Treadmill running until exhaustion (2′ at 10 km/h + 2′ at 12 km/h + increments of 2° inclination per 1′ until 12%)	–		Pre > post (DL and NDL) SMD = − 1.19 to − 1.14 MD = − 10.45 to − 14.86%		Pre > post (DL and NDL) Hip, knee and ankle max linear and ang vel SMD = 0.45 to 1.51 MD = − 6.42 to 13.77%
Radman et al. [110]	Pre-mid-post Randomized Cross-over RM	EX_1: shuttle run max (3′ 20 m at 8 km/h with 180° COD + 3′ rec) with 1 km/h increments until exhaustion EX_2: 7 × 3′ self-selected low-speed running + 3′ rec INT_1: baseline-pre INT_2: blood lactate < 1.5 mmol/L INT_3: blood lactate between 1.5 mmol/L—LT1 INT_4: blood lactate between LT1–LT2 INT_5: blood lactate > LT2 INT_6: max intensity where running cessation	–		INT_1 > post-INT_6 (EX_1) SMD = − 0.58 MD = − 4.25%	INT_1 > post-INT_6 (EX_1) SMD = − 0.63 MD = − 12.72%	
Local all-out high-intensity EX							
Amiri-Khorasani et al. [89]	Pre-mid-post	10 max consecutive kicks without recovery	–		Pre > post SMD = − 4.18 [− 6.84; − 1.52] MD = 5.41%		Pre > post Leg and thigh ang vel SMD = 6.16–6.43 MD = 4.81–6.16%
Amiri-Khorasani et al. [87]	Pre-mid-post	10 max consecutive kicks without recovery	–				Pre > post Concentric max ang vel $P \leq 0.01$

Table 5 (continued)

Study ($N=34$)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Torreblanca-Martinez et al. [13]	Pre-post	15″ max continuous CMJs without recovery	–	Pre = post SMD = −0.10 [−0.81; 0.62] MD = 1.94%			
Local submaximal fixed-intensity endurance EX							
Apriantono et al. [23]	Pre-post	3 × max knee flexion (40% BW–35, 25 and 20 rep) and extension (50% BW–41, 30 and 23 rep), without interval between sets	–	Pre > post SMD = −0.82 [−1.93; 0.28] MD = 4.06%	Pre > post SMD = −1.09 [−2.24; 0.06] MD = 5.63%		Pre > post Shank max ang vel SMD = −0.45 [−1.51; 0.62] MD = −3.77%
Draganidis et al. [93]	Pre-post Randomized Counterbalanced RM	EX_1: control EX_2: 40–45′ strength training [4 × 4 LL exercises × 8–10 rep (65–70% 1RM) with 1′ rec between series] EX_3: 40–45′ strength training [4 × 4 LL exercises × 4–6 rep (85–90% 1RM) with 5′ rec between series]	–			Pre- > post-$EX_{2,3}$ SMD = 1.02 MD = −15.88 to 48.82%	
General all-out endurance EX							
Ferraz et al. [95]	Pre-post	2′ circuit with multiple, short and intense actions (e.g. sprint, skipping, jumping, COD with ball) at 85–95% HR_{max}	–		Pre > post $P < 0.05$ MD = 8.54%		
General submaximal fixed-intensity endurance EX							
Juarez et al. [100]	Pre-post	20′ treadmill running at 80% HR_{max}	–	Pre = post SMD = −0.11 [−0.71; 0.50] MD = 0.54%	Pre = post SMD = −0.18 [−0.43; 0.78] MD = −0.90%		Pre = post Hip, knee and ankle max linear vel SMD = −0.14 to 0.11 MD = −0.72 to 0.91%
Local graded until exhaustion endurance EX							

Table 5 (continued)

Study (*N* = 34)	Design	Exercise protocol (EX)	HT (min)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
McMorris et al. [104]	Pre-post Randomized Counterbalanced RM	EX: Cycle ergometer at 70 rpm: 5′ resting + 2′ at 35 W + 28 W increments per 2 min EX_1: Resting–pre EX_2: EX performed at epinephrine threshold EX_3: EX performed until max power	–			EX_1 = post-$EX_{2,3}$ SMD = −0.88 to −0.14 MD = −95.31 to 29.17%	
Soccer practice EX							
Cariolo et al. [91]	Pre-post	124–134′ soccer practice session	–			Pre = post SMD = −0.17 to 0.49 MD = −16.80 to 31.23%	

SMD standardised mean difference [upper; lower confidence limits or range], *MD* mean percentage difference, *HT* half-time, *RM* repeated measures, *rep* repetitions, *jog* jogging, *max* maximal, *rec* recovery, VO_{2max} maximal oxygen uptake, *INT* intensity, *BW* body weight, *vel* velocity, *COD* change-of-direction, FC_{max} maximal heart rate, *dacc* deceleration, *LIST* Loughborough Intermittent Shuttle Test, *Yo-Yo IRT1* Yo-Yo Intermittent Recovery Test Level 1, *SMS* soccer match simulation, *LT1* first lactate threshold, *LT2* second lactate threshold, *CMJ* countermovement jump, *LL* lower limbs, *DL* dominant limb, *NDL* non-dominant limb, *ang* angular, *disp* displacement. –information not reported or unclear

tions of soccer demands when ball skills were included (SMD = 0.07–0.53). Strong evidence for no significant changes was also observed in sub-elite senior players (SMD = 0.07–0.44) [14, 94, 96], while this evidence was moderate in elite (SMD = 0.10–0.53) [16, 39].

3.5.2.2 Simulated soccer demands without ball skills Moderate evidence for declines in ball velocity were exhibited in senior players (SMD = 0.50–1.37) following simulated soccer demands without ball skills (irrespective of standard) [19, 102, 107]. In sub-elite players, the evidence was conflicting (SMD = 0.02–1.37) [17, 102, 107], while evidence was limited in elite peers (SMD = 1.03) [19]. Limited evidence of impairments was also observed regarding foot velocity (SMD = 1.03) in sub-elite senior players [102]. The same trend occurred regarding ball velocity in sub-elite youth players (SMD = 0.47) [38]. Conflicting results were observed regarding the effects of simulated soccer demands without ball skills on accuracy (SMD = 0.19–2.94) irrespective of playing standard [17–19, 85, 107, 112]. In sub-elite populations, this conflicting evidence persisted (SMD = 0.27–2.94) [17, 18, 85, 107, 112], while there was limited evidence showing no changes in elite senior players (SMD = 0.19) [19].

3.5.2.3 Match-play demands Limited evidence was available regarding the effects of match-play demands on kicking performance according to subgroups/variables of kicking. Two studies, one in sub-elite youth (SMD = 0.12) [114] and the other in elite seniors (SMD = 0.39–0.55) [113], indicated no significant changes in ball velocity following match-play (match simulation used in the former). Declines in ball velocity were observed in a study in elite youth (SMD = 0.57–1.04) [116], while accuracy was not altered in sub-elite youth players (SMD = 0.04) [114], respectively, following competition and simulated matches.

3.5.3 General Intermittent High-Intensity Exercise

Two studies provided limited evidence of the effects of general intermittent high-intensity exercise on kicking accuracy in sub-elite youth players (SMD = 0.09–0.92) [20, 103], while one (also representing limited evidence) reported declines in ball velocity in sub-elite senior players (SMD = 1.06) [21].

3.5.4 General Graded Until Exhaustion Endurance Exercise

Moderate evidence indicated that, in sub-elite senior players, significant declines in ball velocity (SMD = 0.58–1.19) occurred following general graded until exhaustion endurance exercise protocols [64, 101, 110].

3.6 Influence of Recovery-Related Strategies on Soccer Kicking

3.6.1 Overview

Five studies reported data collected immediately after the end of the first-half and prior to the beginning of the second-half during match activity simulations (i.e. general intermittent endurance physical effort). The results revealed that following the 15-min interval (half-time) foot velocity [97], ball velocity [14, 16, 38, 39] and accuracy [14, 16, 39] were not significantly modified. Two studies analyzed the time-course for recovery following cessation of physical exercise [64, 93], while one addressed the effects of a habitual night of sleep versus total sleep deprivation on subsequent kick performance (limited evidence) [109]. Eight studies determined the effects of ergogenic aids on recovery in kicking performance following general intermittent endurance physical efforts (Table 6). These frequently involved pre- [86] or pre/mid-exercise carbohydrate supplementation [14, 17, 18, 39, 85, 117]. The effects of water intake were secondarily addressed (limited evidence) [91, 107]. Finally, six additional studies analyzed the effects of ergogenic aids applied to players in a resting state. Strategies included kinesiotape [106], elastic taping [111], lumbar spine manipulation [92], and compression garments (socks [98, 99] or shorts [115]). Except for the latter, all these strategies demonstrated limited evidence of their impact on soccer kicking performance. A more detailed classification of evidence level is provided below for distinct recovery-related strategies, variables of kicking and subgroups.

3.6.2 Passive Resting

3.6.2.1 Half-time There was strong evidence indicating that passive resting during the 15-min half-time pause did not significantly modify ball velocity in senior players (irrespective of standard) (SMD = 0.16–0.36) [14, 16, 39]. When participants were split according to playing standard, the evidence for no changes in ball velocity following half-time was moderate in elite (SMD = 0.17–0.36) [16, 39] and sub-elite senior (SMD = 0.16) [14] and limited in sub-elite youth players (SMD = 0.58) [38].

3.6.2.2 Time-course of changes Limited evidence was observed for the effects of additional passive resting conditions on kicking performance, such as in time-course studies. The acute decrease in accuracy as a result of a strength training session applied to lower limbs was reestablished within 24 h (MD = − 16.12 to 15.19%), in a study using sampling windows of 1 day (until 3 days after exercise being completed) [93]. When 30 s intervals were interspersed between repeated measures of kicking performance, approximately 1 min was sufficient to recover declines in ball velocity induced by an incremental running protocol until exhaustion (SMD = 0.43–0.45) [64].

3.6.3 Ergogenic Aids

3.6.3.1 Carbohydrate provision In sub-elite senior players, evidence on the effects of pre/mid-exercise carbohydrate supplementation on kicking accuracy (SMD = 0.13–0.57) was conflicting [14, 17, 18, 85], while there was moderate evidence of no significant effects regarding ball velocity (SMD = 0.18–0.41) [14, 17]. Moderate evidence indicated that, in elite senior players, pre/mid-exercise carbohydrate supplementation produced significant effects on ball kicking velocity (SMD = 0.67) but not accuracy (SMD = 0.01) [39].

3.6.3.2 Electrical stimulation A separate study provided limited evidence that low-frequency electrical stimulation, applied at the half-time pause in simulated soccer match-play demands, had a significant effect on subsequent kicking ball velocity in sub-elite youth players (SMD = 0.56) [38].

3.6.3.3 Compression garments There was moderate evidence that using either high or low compression shorts did not modify ball velocity in sub-elite senior players (SMD = 0.09–0.12) [115].

4 Discussion

The purpose of the current analysis was to systematically review and critically appraise original research articles in the scientific literature addressing the acute effects of warm-up, exercise and/or recovery-related intervention strategies on ball kicking kinematics and performance in male soccer players. In general, task constraints used across studies to testing kick performance generally lacked real-world resemblance to the competition environment, while simple notational-based outcome measures of accuracy were generally adopted. Most evidence derived from the interventions synthesized was associated with moderate level and unclear-to-high risk of bias. Nevertheless, the results showed that kicking performance improved following warm-ups involving dynamic but not static stretching. Intermittent or graded until exhaustion endurance exercise without inclusion of ball skills impaired subsequent ball kicking velocity, while accuracy was less frequently affected by exercise. Carbohydrate supplementation pre- and mid-exercise demonstrated some

Table 6 Effects of recovery-related strategies on soccer kicking performance reported in studies included in the review

Study (N = 21)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Passive resting							
Beliard et al. [38]	Pre-post	36′: 3 bouts × 12′ (standing + walking + jogging + running + sprinting)—SAFT^{90} [123]	15′ resting after EX (half-time pause)		Pre vs. post SMD = − 0.58 [− 1.19, 0.02] MD = − 5.13%		
Greig [97]	Pre-post	3 × 15′ intermittent treadmill running simulating match-play bouts (stationary, walking, jogging, cruising and sprinting) [126]	15′ resting after EX (half-time pause)	Pre = post SMD = − 0.58 [− 0.32; 1.48] MD = 5.47%			Pre = post Thigh and shank ang disp and pelvic orientation SMD = − 0.15 to 0.56 MD = − 4.38 to 18.17%
Russell et al. [39]	Pre-post	45′ (7 rep × 4.5′ exercise, 3 repeated cycles: 3 × 20 m walking, 1 × side walking, 1 × 15 m sprint or 20 m dribble + 4″ rec + 5 × 20 m jog at 40% VO_{2max} + 20 m backward jog at 40% VO_{2max} + 2 steps × 20 m at 85% VO_{2max} + 2′ passing + 1′ rec)—SMS [125]	15′ resting after EX (half-time pause)		Pre = post SMD = 0.17 [− 0.54; 0.89] MD = 1.09%	Pre = post SMD = − 0.04 [− 0.76; 0.67] MD = − 2.06%	

Table 6 (continued)

Study (N = 21)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Russell et al. [16]	Pre-post	45′ (7 rep × 4.5′ exercise, 3 repeated cycles: 3 × 20 m walking, 1 × side walking, 1 × 15 m sprint or 20 m dribble + 4″ rec + 5 × 20 m jog at 40% VO_{2max} + 20 m backward jog at 40% VO_{2max} + 2 steps × 20 m at 85% VO_{2max} + 2′ passing + 1′ rec)—SMS [125]	15′ resting after EX (half-time pause)		Pre = post SMD = − 0.36 [− 1.09; 0.36] MD = − 3.16%	Pre = post SMD = 0.95 [0.19; 1.71] MD = 32.42%	
Stevenson et al. [14]	Pre-post	45′ adapted version of the SMS [125]	15′ resting after EX (half-time pause)		Pre = post SMD = -0.16 [− 0.75; 0.43] MD = − 2.19%	Pre = post SMD = − 0.36 [− 0.95; 0.24] MD = − 15.33%	
Draganidis et al. [93]	Pre-post Randomized Counterbalanced RM	EX_1: control EX_2: 40–45′ strength training [4 × 4 LL exercises × 8–10 rep (65–70% 1RM) with 1′ rec between series] EX_3: 40–45′ strength training [4 × 4 LL exercises × 4–6 rep (85–90% 1RM) with 5′ rec between series]	RES_1: 24 h after EX RES_2: 48 h after EX			Post-EX < $RES_{1–2}$ $P < 0.05$ MD = 11.92–124.83% $RES_1 = RES_2$ $P > 0.05$ MD = − 16.12 to 15.19%	
Katis et al. [64]	Pre-post RM	Treadmill running until exhaustion (2′ at 10 km/h + 2′ at 12 km/h + increments of 2º inclination per 1′ until 12%)	RES_1: 30″ resting after EX RES_2: 60″ resting after EX		Post-EX vs. $RES_{1,2}$ SMD = − 0.43 to 0.45 MD = − 4.58 to − 5.11% RES_1 vs. RES_2 SMD = − 0.04 [− 0.84; 0.92] MD = − 0.50%		
Pallesen et al. [109]	Post-only Randomized Counterbalanced RM	–	RES_1: habitual sleep night RES_2: 24 h of total sleep deprivation			$RES_1 > RES_2$ SMD = 0.17 [− 0.47; 0.80] MD = 1.71%	

Table 6 (continued)

Study ($N=21$)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Ergogenic aids (pre/mid-exercise)							
Abbey and Rankin [85]	Mid-post Randomized	5×3 rep 15′ (jog 55% VO_{2max} + running at 120% VO_{2max} + walking + jog at 55% VO_{2max} + sprint max)	RES_1: placebo RES_2: 6% carbohydrate-rich drink—1 g/kg (pre/mid-EX) RES_3: RES_1 + honey sweetened (pre/mid-EX)			$RES_1 = RES_{2,3}$ SMD = −0.23 to −0.13 MD = −5.83 to −2.89%	
Abt et al. [86]	Pre-post Randomized RM	60′ treadmill running (reps 5′ at 12 km/h and 2.5° + 30″ at 12 km/h and 7° + 75″ at 4 km/h and 0° inclination)	RES_1: control RES_2: 48 h diet (80% carbohydrate, 10% fat and 10% protein) (pre-EX)			$RES_1 = RES_2$ SMD = 1.01 [−0.23; 2.24] MD = 7.09%	
Ali et al. [17]	Pre-post Randomized Double-blind Cross-over RM	6×15′×10–12 rep (walking + running at 95% VO_{2max} + jog at 55% VO_{2max} + sprint + 3′ resting)—LIST [122]	RES_1: placebo RES_2: 6.4% carbohydrate-rich drink—2–5 mL/kg (pre/mid-EX)		$RES_1 = RES_2$ SMD = 0.41 [−0.29; 1.12] MD = 2.95%	$RES_1 < RES_2$ SMD = 0.42 [−0.28; 1.12] MD = 16.67%	
Beliard et al. [38]	Pre-mid-post Randomized RM	2×36′: 3 bouts × 12′ (standing + walking + jogging + running + sprinting)—SAFT[90] [123]	RES_1: placebo RES_2: low-frequency electrical stimulation on the medial/lateral calf at half-time pause (mid-EX)		$RES_1 < RES_2$ SMD = −0.56 [−0.93; −0.04] MD = −4.8%		
Currell et al. [18]	Pre-mid-post Randomized RM	10×6′ [4 rep 90″: 10″ walking + 2×(10″ jog at 50% max vel + 10″ at 95% max vel) + 15″ walking + 5″ sprint + 15″ jog at 50% max vel + 5″ sprint]	RES_1: placebo RES_2: 7.5% carbohydrate-rich drink—1 mL/kg (pre/mid-EX)			$RES_1 < RES_2$ $P = 0.01$ MD = 3.5%	

Table 6 (continued)

Study ($N = 21$)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Kaviani et al. [117]	Pre-mid-post Randomized Counterbalanced Double-blind Cross-over RM	10 × 6′ (alternated between 60 m walking at 25% max int, 60 m jogging at 55% max int, 60 m running at 95% max int and 20 m sprinting)	RES_1: consumption of nutrition bar (0.38–1.5 g/kg) glycemic index 45 (pre/mid-EX) RES_2: consumption of nutrition bar (0.38–1.5 g/kg) glycemic index 10 (pre/mid-EX)			$RES_1 = RES_2$ SMD = 0.10 [−0.88; 1.09] MD = 5.07%	
Russell et al. [39]	Pre-mid-post Randomized Double-blind Cross-over RM	2 × 45′ (7 rep × 4.5′ exercise, 3 repeated cycles: 3 × 20 m walking, 1 × side walking, 1 × 15 m sprint or 20 m dribble + 4″ rec + 5 × 20 m jog at 40% VO_{2max} + 20 m backward jog at 40% VO_{2max} + 2 steps × 20 m at 85% VO_{2max} + 2′ passing + 1′ rec)—SMS [125]	RES_1: placebo RES_2: 6% carbohydrate-rich drink—3.5 mL/kg (pre/mid-EX)		$RES_1 < RES_2$ SMD = 0.67 [−0.07; 1.41] MD = 4.55%	$RES_1 = RES_2$ SMD = 0.01 [−0.71; 0.72] MD = 0.36%	
Stevenson et al. [14]	Pre-mid-post Randomized Double-blind Cross-over RM	2 × 45′ + 2 × 15′: adapted version of the SMS [125] including extra-time	RES_1: placebo RES_2: maltodextrin + 8% carbohydrate-rich drink RES_3: isomaltulose + 8% carbohydrate-rich drink (pre/mid-EX)		$RES_1 = RES_{2,3}$ SMD = −0.18 to 0.18 MD = −2.27 to 4.35%	$RES_1 = RES_{2,3}$ SMD = −0.57 to 0.49 MD = −30 to 15.38%	
Water intake							
Cariolo et al. [91]	Pre-post RM	124–134′ soccer practice session	RES_1: ad libitum water consumption RES_2: prescribed water consumption (to cover 100% sweat loss) (mid-EX)			$RES_1 < RES_2$ SMD = −0.27 to 0.31 MD = −27.51 to 12.4%	

Table 6 (continued)

Study ($N = 21$)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results			
				Foot velocity	Ball velocity	Accuracy	Additional kinematics
Owen et al. [107]	Pre-post Randomized RM	6 blocks × 15′ × 11 rep (20 m walking, sprint, running at 95% VO_{2max} + jog at 55% VO_{2max}), with 3′ interval between blocks—LIST [122]	RES_1: without fluid ingestion RES_2: ad libitum water consumption (mid-EX) RES_3: prescribed water consumption (to cover 100% sweat loss) (mid-EX)		$RES_1 = RES_{2,3}$ SMD = − 0.28 to − 0.06 MD = − 1.73 to − 0.39%	$RES_1 = RES_{2,3}$ SMD = − 0.18 to 0.17 MD = − 9.09 to 7.69%	
Ergogenic aids (rested players)							
Deutschmann et al. [92]	Pre-post Non-randomized Single-blind	–	RES_1: sham laser RES_2: lumbar spine manipulation RES_3: sacroiliac joint manipulation RES_4: $RES_1 + RES_2$		Pre < post ($RES_{2–4}$) $P \leq 0.009$ MD = 3.76–5.76%		
Hasan et al. [99]	Post-only Randomized RM	–	RES_1: smooth socks with smooth insoles–control RES_2: smooth socks with textured insoles RES_3: compression socks with smooth insoles RES_4: compression socks with textured insoles				$RES_1 = RES_{2–4}$ Hip and knee ROM SMD = − 0.21 to − 0.13 MD = − 4 to − 1.69%
Hasan et al. [98]	Post-only Randomized RM	–	RES_1: smooth socks with smooth insoles–control RES_2: smooth socks with textured insoles RES_3: compression socks with smooth insoles RES_4: compression socks with textured insoles	$RES_1 = RES_{2–4}$ SMD = − 0.16 to 0.01 MD = − 1.19 to 0.09%	$RES_{1,2} < RES_3$ SMD = − 0.43 to − 0.36 MD = − 6.25 to − 5.23%		$RES_2 < RES_{3,4}$ Ankle flex/ext ROM SMD = − 0.47 to − 0.39 MD = − 3.05%
Muller and Brandes [106]	Post-only Randomized	–	RES_1: without kinesiotape RES_2: using kinesiotape		$RES_1 < RES_2$ SMD = − 0.19 [− 0.35; 0.73] MD = − 1.79%	$RES_1 > RES_2$ SMD = 0.66 [0.10; 1.22] MD = 10.78%	

Table 6 (continued)

Study ($N=21$)	Design	Prior exercise (EX)	Recovery-related strategy (RES)	Main results: Foot velocity	Ball velocity	Accuracy	Additional kinematics
Otten et al. [115]	Post-only Randomized Double-blind RM	–	RES_1: no compression short RES_2: zoned high compression short RES_3: non zoned low compression short		$RES_1 = RES_{2,3}$ SMD = −0.12 to −0.09 MD = −1.35 to −1.01%		
Sasadai et al. [111]	Randomized RM	–	RES_1: without elastic taping RES_2: elastic taping–0° plantar flexion RES_3: elastic taping–15° plantar flexion RES_4: elastic taping–30° plantar flexion	$RES_1 = RES_{2–4}$ SMD = −0.08 to 0.15 MD = −0.67 to 1.33%	$RES_1 > RES_{2,3}$ SMD = 0.83–1.55 MD = 6.1–11.7%		$RES_1 > RES_{2–4}$ Max ang plantar flex SMD = 0.8–2.09 MD = 19.95–53.13%

SMD standardised mean difference [upper; lower confidence limits or range], *MD* mean percentage difference, *RM* repeated measures, *rep* repetitions, *jog* jogging, *max* maximal, *rec* recovery, *int* intensity, *SMS* soccer match simulation, *LIST* Loughborough Intermittent Shuttle Test, *LL* lower limbs, *ROM* range-of-motion, *ang* angle, *disp* displacement, *flex* flexion, *ext* extension. –information not reported or unclear

benefits in counteracting the deleterious effects of endurance exercise on ball velocity in senior elite but not sub-elite players.

4.1 Research Paradigm

4.1.1 Methodological Quality and Samples

Overall, a moderate mean methodological rating was observed across studies with these generally providing sufficient information to characterize study samples. However, essential information relating to the data collection environment and ball standardization (e.g. dimensions/pressure) was frequently omitted. In addition, selective reporting occurred, blinding aspects were poorly accounted for, and allocation concealment was not always ensured. These sources of bias are limitations to the current evidence base, thereby implying caution when interpreting and/or applying the findings collated here. Finally, adult players were predominantly investigated (42/52 studies). Accordingly, additional research in youth players across different age categories is warranted especially as kicking kinematics and performance are strongly age dependent [62, 63, 127].

4.1.2 Kicking Tasks

Scientific studies investigating the biomechanics of kicking tend to demonstrate substantial citation rates [128]. Yet, the practical applications of available research findings are still debatable with perhaps a need for more holistic real-world approaches to investigating kicking performance [34]. Indeed, the conditions in which the mechanics and accuracy of the kicking task were evaluated along with associated contextual constraints merit scrutiny. First, discrepancies were noted regarding instructions provided to the participants on how they should perform kicking actions. Instructions on both velocity and accuracy were only provided in approximately 27% of the selected studies [15, 19, 23, 48, 50, 64, 88, 94, 96, 101, 105, 106, 108, 110]. A single study also instructed players to hit a target with 'realistic velocity' (match specific) [110]. In contrast, in 62% of the studies, subjects were asked to kick maximally without explicit instructions relating to accuracy or were instructed to hit a target without directives on ball velocity (Table 2).

There is evidence supporting Fitts' law [129] which indicates a trade-off between velocity and accuracy in soccer kicking [28], and research demonstrates that the provision of instructions emphasizing both velocity and accuracy can reduce bias in these variables [27]. The distance at which kicks were taken from the goal is an additional factor potentially influencing the balance between kick velocity and accuracy [33]. In over half of the studies (see Table 3), kicks were taken at a distance of 11-m from the goal (e.g.

penalty kick simulations) [21, 23, 37, 48, 50, 90, 94–96, 102, 108] or from shorter distances [15, 20, 38, 47, 49, 51, 64, 87–89, 98–101, 103–106, 109, 115, 116]. This limitation reduces the extrapolation of these research findings to other frequent game actions. For example, kicks from distance (e.g. taken outside the penalty area) are frequent in soccer [130, 131] but received less attention in the literature (< ¼ studies [16–18, 39, 85, 86, 93, 110, 112, 117]). Similarly, players were instructed to kick at the center of the goal more frequently than to the corner areas. Utilizing targets positioned only in the goal center suggests lower external validity as this zone is where goalkeepers generally stand prior to an opponent kicking the ball [27]. Kicks were also mostly examined in the absence of opposition except for two studies that used wooden static goalkeepers [17, 107]. The absence of opposition players such as goalkeepers (i.e. human) or defenders during a kick can bias results [29, 30]. Approach run velocity is constrained by the initial distance of the opponent as well as by its simple presence during task performance. Hence the expression of kicking behaviour is highly modulated by the context; if a defender is not present as a task constraint, some movement regulation features would likely not emerge [30]. Future work should therefore consider the inclusion of opponents contesting kicks and more match-realistic conditions in an attempt to augment the ecological validity of kicking kinematic analyses whilst also reporting between-trials consistency measures.

A further issue concerned the players' approach to the ball when performing a kicking action. Arguably, imposing constraints on the approach run can alter kicking patterns [62, 68], yet when the initial player position (e.g. distance to the ball or approach angle) was not controlled or measured in experimental designs it likely added undesirable variance across trials, particularly in movement mechanics in the later stages of the task (i.e. impact phase) [72, 132]. While players frequently vary their approach run in match-play conditions making experimental design difficult, the lack of consistency across studies (presented in Sect. 3.3.2) nevertheless influences interpretations of the potential effects of any intervention used to test changes in kicking performance as well as rendering difficult comparisons of findings across the literature. Overall, it is difficult to directly apply some of the findings from the current literature to the performance environment [133] and these methodological limitations indicate a need to reconcile study designs with the real-world demands of soccer competition.

4.1.3 Data Acquisition Methods

Foot velocity is considered to be one of the main variables in lower limb movement kinematics, because it largely reflects the momentum transferred via proximal–distal interaction between body segments when kicking [134]. Ball velocity and accuracy are also recognized as key indicators of kicking performance [1, 36, 135, 136], being also strongly associated with limb movement kinematics [77, 134, 137]. Given the theoretical relationships between ball flight behavior and additional lower limb features (e.g. striking mass) [138, 139], it seems reasonable to suggest that when the inertial properties of the impact segment remain relatively invariable throughout a testing session, standardization of the ball characteristics is essential. However, standardization was systematically omitted as less than half of the studies provided key information on ball dimension [14–16, 19, 89, 94–96, 98, 99, 114, 115] and only a quarter additionally reported ball pressure [23, 37, 47–49, 51, 87, 88, 90, 101, 105, 111] (Table 2). Ball size [140, 141] and pressure [69] influence foot–ball impact and subsequent kicking performance and this information should be reported and standardized (see review by Lees et al. [1]).

Across the literature, ball velocity was generally calculated using either radar or video kinematic systems. Preliminary data indicate a strong association ($r = 0.994$) between ball kicking velocity obtained via radar and 2-D video kinematic systems [142]. Ball angular trajectory and velocity analyses of softball batting also demonstrated agreement (to within 0.09 rad and 2 m/s, respectively) between radar and video kinematic (3D) outcomes, suggesting potential interchangeability of data [143]. Replication studies using soccer kicking are required to confirm concurrent validity of radar outcomes against gold-standard measures, given the 3D nature of the task [1] which may be distorted/underestimated in 2D procedures [144]. Given that video kinematic systems generally require specialized staff for data processing, a laboratory setting, and high costs [145], radar is a pertinent alternative especially in practical settings. However, while information on the positioning of radars was generally provided [15, 19, 38, 50, 92, 94–96, 108, 114, 115], data on sensitivity and measurement error were less frequently provided (41% of studies [15, 19, 92, 94–96, 115]), while acquisition frequency was rarely described [19, 114] thereby rendering difficult comparisons across study findings.

It is recognized that there are discrepancies in lower limb distal extremity velocities during the impact phase of kicking, with a difference in amplitude of up to ~ 10 m/s depending on the region of the foot or ankle used for the calculations [146]. Consequently, a lack of conformity regarding the number of markers used and their positioning to calculate foot velocity (fully described in Sect. 3.3.3) suggests caution when attempting to directly compare results from studies using video kinematic systems. Conversely, while a standard marker set configuration for foot kinematic analysis has not yet been defined in literature [147], it may have contributed to the aforementioned issue. Similarly, critical appraisal of the sampling and filtering procedures used prior to extraction of movement kinematics revealed discrepancies.

Nunome and collaborators [32] demonstrated that using an automatic time–frequency filter together with high acquisition frequency (1000 Hz) was efficient in identifying sudden changes in the lower limb kinematics during the ball impact phase. In contrast, these changes were not observed at a lower sampling rate (250 Hz) and after traditional filtering (i.e. Butterworth in low and constant cut-off frequency). In investigations quantifying lower limb kinematics and foot velocity, acquisition frequencies ranged from 50 to 500 Hz (Table 2)—all below or equal to half the frequency recommended [32]. In addition, a Butterworth filter was also used in 37% of cases (cut-off frequency ranging from 12–16 Hz) [37, 49, 64, 99, 101, 102, 111] otherwise the filtering procedure was not described in 47% [13, 47, 48, 87–90, 97, 105]. Alternative data treatment techniques potentially useful for time-series data are also available. These include extrapolation [148], quintic spline [66], robust non-parametric locally weighted function [68] and most recently a modified fractional Fourier filter [149]. However, only a few studies (16%) considered these techniques [23, 98, 100]. Given the absence of a clear consensus on best practice regarding minimum sampling rates in analyzing kicking parameters and how to correctly filter time-series, some research groups have also ruled out impact data as input arguments to the smoothing program [65, 66, 68] aiming to minimize systematic error.

Although the use of video kinematic systems has become more frequent compared to the beginning of the 2010s [11], kicking accuracy was still mostly determined by simple notational-based methods (Table 2 and Sect. 3.3.3). Outcome metrics included the total/percentage number of kicks hitting a given target or using criterion measures (e.g. punctuations) arbitrarily defined according to ball placement when it crosses the goal line. Questions have been raised concerning the reliability, objectivity, and sensitivity of such metrics [11, 63, 150, 151]. For example, studies included in the current review reported that: (1) ballistic compared to static stretching improved accuracy when computed as the deviation from the target, but this was not the case when the number of total missed kicks (ball outside the target) was computed [51]; (2) an exercise protocol of a similar duration to a match did not significantly affect the percentage of successful kicks (ball contacted the goal or target) but increased the absolute deviation of the ball from the target [16] and, (3) a large beneficial effect (SMD = 0.95; ~ 32%) was observed for ball deviation from a target after a 15-min half-time pause, whereas changes in success percentage (ball contacted the goal/target) were small (SMD = 0.47; ~ 16%) [16]. Thus, it is arguably necessary that future research moves beyond simple gross measures of accuracy and is reconciled more with real-world characteristics of play. Indeed, work has shown that scores in a commonly used field test of technical performance lacked validity in relation to actual competition demands [25].

4.2 Kinematics and Performance of Soccer Kicking Following Interventions

4.2.1 Warm-Up

Warm-up routines are performed prior to competitive events and training sessions to enhance readiness for subsequent performance [41]. Moderate evidence here suggests that kicking accuracy in youth sub-elite players, and ball velocity in senior sub-elite and elite players, are both improved following a warm-up consisting of dynamic stretching but not static stretches. These observations corroborate those reported in another two reviews that detected analogous results in soccer physical capacity as a consequence of applying dynamic versus static stretching exercises in the warm-up [40, 42]. Both kicking accuracy and ball velocity are governed by movement kinematics and muscle activation of the kicking limb [77, 134, 137]. Static stretching exercises are typically part of soccer warm-up routines [40]. These are often considered easier and safer to apply in comparison to other modalities [152, 153] and may not modify lower limb kinematics in vigorous lower limb muscle contractions [154]. However, static stretching acutely decreases neuromuscular activity [155–157], while footballers might also perceive greater effort when performing passive static stretching compared to ballistic stretching exercises of equalized volume [158]. Accordingly, preference should be towards inclusion of dynamic exercises in warm-ups, while static stretching routines only should specifically be avoided immediately prior to testing kicking performance. In addition, while a combination of short static stretching exercises followed by dynamic movements has positive effects on physical performance measures [41, 159, 160], only limited evidence is available to date regarding their effects on kicking output [50].

A previous systematic review of the literature showed that when performing explosive athletic tasks, a specific preparation is required which is frequently not matched by the traditional warm-ups in most of the football codes [41]. Warm-up routines commonly performed in soccer include locomotor activities, resistance tasks, and specific drills [40] and not only simple running exercises followed by stretching [161]. Among strength exercises included in warm-ups prior to kicking evaluations, only unloaded squats using both lower limbs were tested [108]. However, kicking and other soccer actions (e.g. sprinting, jumping and change of direction) are commonly performed unilaterally or with the weight transferred to one leg at a given moment [162]. Additionally, the evidence of the effects of a game-specific technical warm-up (e.g. ball juggling plus wall volley exercise) is limited [105]. In sum, a closer resemblance between the protocols used in practical contexts and those in research studies is again necessary. For example, to establish the effects of common pre-exercise practices, studies should include loaded strength stimuli, specific skill tasks as well as technical–tactical exercises (e.g. small-sided games) [40].

When prescribing and tailoring warm-up routines to ensure readiness to perform, external constraints (i.e. logistics) must typically be accounted for [163] and one example is the transition time between the end of the warm-up and the performance test. In studies verifying the beneficial effects of warm-up on kicking parameters, transition time ranged from 1 min [51], most commonly 2 min [37, 47–49, 88, 90] to a maximum of 5 min [50]. In the sole study not detecting any difference in kicking outcomes, it is noteworthy that there was a very short interval following the warm-up (20 s) [105]. Yet analysis of warm-up strategies in professional soccer competition showed this duration can be substantially longer [52]. While the current literature generally reports beneficial effects of a warm-up on kicking performance, the transition time from warm-up to performance testing might be considered suboptimal across studies. According to a meta-analysis [164], a 7–10-min rest period following cessation of the warm-up routine enhanced ensuing power performance; it is likely that a balance favouring increases in muscle contractile response and dissipation of transient fatigue is achieved to a greater magnitude within this time-window than using shorter periods. However, the question arises as to the duration that the benefits gained from a given warm-up persist as specifically regards kicking velocity? Also, kicking performance should be also assessed after longer rest periods, for example, between the pre-match warm-up end and subsequent evaluation, in an attempt to improve ecological validity through respecting the realities of the competition setting. Indeed, work has reported a time interval lasting an average of 12.4 min (standard deviation = 3.8) interval between the end of the warm-up and match kick-off [52].

4.2.2 Exercise

In general, analyses of ball kicking velocity most frequently reported a decline following exercise although exercise-induced effects on velocity were dependent on the type of protocol utilized. Moderate evidence indicates ball velocity reductions in senior players following general intermittent endurance efforts without inclusion of any ball skills, despite mixed results observed in subgroups across different competitive standards (limited evidence of declines in elite and conflicting outcomes in sub-elite players). Most specifically in sub-elite senior players, the velocity of the ball declined following general graded until exhaustion endurance exercise while no significant changes were observed as a consequence of general intermittent endurance exercise interspersed with execution of ball skills (moderate evidence in both cases). Thus, when exercise protocols prioritized locomotor capacity without inclusion of ball skills, a greater acute negative impact on subsequent kicks tended to occur. Conversely, intermittent endurance physical activity interspersed with execution of ball skills reported lower effects on subsequent ball velocity. Indeed, the inclusion of ball drills in exercise circuits can reduce both perceived effort [165] as well as actual exercise intensity [166] possibly aiding reduction of any transient effect of fatigue on kicking capacity and this needs to be taken into account when designing experimental protocols.

While declines in neuromuscular outputs in match-play simulations are elicited mainly due to central fatigue occurrence, these appeared to insignificantly modify kicking velocity measured at the end of the protocols [9, 167]. In a number of exercise protocols reviewed, there was a generally acceptable degree of relationship between performance outcomes (i.e. 6 × 40 m repeated sprints, Yo-Yo intermittent recovery test level 1, laboratory treadmill exhaustive effort) and running activity performed in actual match-play (i.e. construct validity supported) [168–170], while others (e.g. soccer match simulation, Loughborough Intermittent Shuttle Test and SAFT^{90}) are reported to achieve similar loading to that required in a soccer match [122, 123, 125]. Yet only limited evidence was obtained from the current scientific literature on the consequences of match-play demands (11 versus 11) on components of kicking performance. Additional research is arguably necessary to improve understanding of the effects of game-related fatigue on kick kinematics and performance. Assessments of potential impairments of kicking ability following occurrence of intense periods of locomotor activity (e.g., peak periods of high-intensity running commonly observed in match-play) are merited. Exercise protocols also need to combine physical, technical and tactical elements and better respect the stochastic nature of match running activity [171]. Match physical demands have also substantially evolved over recent years [172] and future exercise testing protocols should account for this change.

In contrast to ball velocity, kicking accuracy was less frequently affected by exercise. There are three possible explanations for this discrepancy. First, where decreased velocities were generally observed due to exercise, kicking accuracy might have been favored; in other words, existence of the velocity–accuracy trade-off [28, 74, 173]. Second, the inability to shoot within the prescribed time requirements of tests can result in poorer shooting scores, rather than assessing the ability to shoot on target [112]. Third, fatigue seems to affect to a greater extent the muscle properties in charge of generating force compared to movement coordination in explosive tasks using the lower limbs [174, 175]. The first two premises might be more plausible, since it is still unclear whether there is a dominance of coordination over force on the control of kicking accuracy [176]. Work is required to explore whether kicks dependent on high ball velocity (e.g.

taken from longer distances to the goal) demonstrate greater impairments as a consequence of exercise-induced fatigue compared to those placing greater demands on controlling ball placement rather than velocity. Integrating analyses of cognitive skills such as decision-making demands and visual searching would also be pertinent.

4.2.3 Recovery-Related Strategies

Studies using game-play running activity simulations [14, 16, 38, 39, 97] identified that a 15-min half-time pause spent in passive recovery did not modify kicking performance (notably velocity outputs). The level of evidence for ball velocity outcomes was moderate in elite and sub-elite senior players, while strong evidence was obtained when pooling all senior players. Indeed, a passive rest during the pause generally led to decrements in muscle temperature which can subsequently inhibit lower limb power performance [177, 178]. Thus, reducing the time spent resting passively could be beneficial for tempering possible previous declines in kicking velocity. While work has shown positive results of such practice on running outputs in simulated or friendly matches [178, 179] no evidence exists for kicking performance [180].

Inadequate recovery during and following competition can impair subsequent athletic performance and potentially predispose players to injuries [181]. Intervention strategies to accelerate recovery are thereby warranted. Investigations of the effects of a carbohydrate replacement on kicking accuracy and velocity showed contrasting results. Conflicting evidence was observed for kicking accuracy in sub-elite senior players while moderate evidence for no significant effects was observed in elite senior peers, which is unsurprising since kicking accuracy is seemingly less affected by exercise. In contrast, moderate evidence pointed to a significant effect following consumption of a carbohydrate-rich drink in counteracting the potential impact of fatigue on ball velocity in elite senior players following extended physical efforts, which is in agreement with previous reviews [46, 182]. Since decreased muscle glycogen stores occurring at the end of senior soccer matches can affect knee extension force generated [183], a carbohydrate supplementation over prolonged exercise might prevent muscle force decrements and also help preserve functioning of the CNS [184] as well as general running activity [185]. Associations between strength measurements and kicking velocity are sometimes unclear [36, 167] but central inputs play an important role in modulating performance of goal-directed sport skills [186, 187]. However, the question arises as to what is the real-world impact of the reduction observed here in ball velocity due to exercising (e.g. overall percentage and raw changes respectively equals approximately 6% and − 1.41 m/s in senior players across studies) on match technical performance outputs. An inverse relationship ($R^2 = 0.82$) between ball velocity and the likelihood a shot is saved by a goalkeeper was shown in a controlled setting [135].

Other recovery methods are also used ubiquitously in soccer [43] yet their effects on kicking performance remain unknown (e.g. cooling techniques in extreme temperature) [188]. Furthermore, single studies [38, 92, 106] or those conducted by the same research group [98, 99] provided only limited evidence on the effects of using of some therapeutic methods for recovery (e.g. electrical stimulation, kinesio-tape and massage). Further replication studies particularly considering inclusion of demands during extended physical effort in addition to these interventions are necessary to confirm whether these common strategies [43] aid recovery of kicking performance during and following exercise. Finally, sleep is recognized as an important recovery process [43, 80, 189, 190]. However kicking performance following habitual sleep nights was compared only to that after total sleep deprivation [109] which is not the most common sleep-related issue in athletic populations (compared to disrupted or partial sleep deprivation) [191, 192].

4.3 Limitations of Included Studies

Over the course of this review, five main limitations of studies were identified. First, critical risk of bias related to blinding of participants, outcome assessor and selective reporting of results, indicates that these aspects should be more carefully treated in future research. However, some procedures are not always feasible in applied research in team sports [193]. Second, methods notably varied across studies and in addition to the mentioned potential risk of bias, pooling the data of interventions in a meta-analysis was deemed inappropriate. Third, intervention protocols were not completely reported in the methods of eight studies (15%) [37, 47–49, 88, 90, 91, 113]–for example, details of the duration, type of exercise, number of exercises and series performed. Fourth, while 33% of all studies clearly reported that kicks were performed using the dominant limb, 56% omitted this information while another 15% allowed players to use both limbs or self-select the lower limb, which may have influenced response to the interventions. Finally, kicking velocity [194] and match physical loads [195] in soccer vary substantially according to positional role yet only two studies [86, 116] accounted for this parameter.

4.4 Limitations of the Current Review

There are several limitations of the current review. A decision was made to only include studies written in English which could have resulted in the loss of research published in other languages. The checklist adopted here was adapted from a previous study [59] which has also served as basis for two recent reviews [168, 196]. However, as outlined in recent critiques [197], our choice for a non-validated tool in appraising methodological quality of comparator trials can be considered another limitation. The qualitative synthesis produced has been based on and is likely influenced by the risk of sources of bias identified. In addition, only half of the studies considered for review employed randomized designs including a control condition. Six studies investigated the effects on kicking performance of ergogenic aids applied to players only in a resting state, and therefore, these results may not be feasibly extrapolated to a mid/post-exercise recovery-focused purpose. Finally, we noted during the literature search and this was also highlighted in a recent publication [198], that studies in women's soccer are insufficient in number and, therefore, the synthesis presented here comprised only male players.

5 Conclusions

To conclude, moderate evidence indicates that a warm-up composed of dynamic stretching is shown to be beneficial for ensuing kicking accuracy (in youth sub-elite players) or ball velocity in senior players (sub-elite and elite), while static stretching only can impair velocity outputs. Research conducted in sub-elite senior soccer (moderate evidence) demonstrates that the velocity of the ball was notably reduced following general graded until exhaustion endurance exercise while no changes occur after general intermittent endurance efforts interspersed with execution of ball skills. Accuracy is less frequently hampered by prior physical exercises demands. Moderate evidence indicates that a passive recovery during the half-time pause did not modify ball kicking velocity (in elite and sub-elite senior players), while benefits of consuming carbohydrate-rich drinks before and during extended exercise were observed in senior elite but not in sub-elite players. Higher quality studies with low risk of bias are necessary to investigate the benefits of habitual soccer warm-up modalities, recovery-related interventions as well as the effects of official match-play (11 vs 11) demands on kicking kinematics. There is a general need to re-examine methodological protocols to improve ecological validity in testing soccer kicking performance.

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Declarations

Conflict of interest Luiz Henrique Palucci Vieira, Felipe Balistieri Santinelli, Christopher Carling, Eleftherios Kellis, Paulo Roberto Pereira Santiago and Fabio Augusto Barbieri declare that they have no conflict of interest relevant to the content of this review.

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Data Availability Statement All raw data supporting this systematic review are from previously reported studies, which have been cited. Additional processed data that support the findings of the current review are available from the corresponding author upon request.

Author contributions LV and FB designed the research. FB, CC and PS supervised the research activity planning and execution. LV and FS conducted the literature search, screening steps and data extraction, which were verified by EK. LV, FS, CC, EK, PS and FB interpreted the data analysis. LV and CC wrote the first draft of the manuscript with critical input from FS, EK, PS and FB. All authors read and approved the final manuscript.

References

1. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: a review. J Sports Sci. 2010;28(8):805–17. https://doi.org/10.1080/02640414.2010.481305.
2. Castellano J, Casamichana D, Lago C. The use of match statistics that discriminate between successful and unsuccessful soccer teams. J Hum Kinet. 2012;31:139–47. https://doi.org/10.2478/v10078-012-0015-7.
3. Liu H, Hopkins WG, Gómez M-A. Modelling relationships between match events and match outcome in elite football. Eur J Sport Sci. 2016;16(5):516–25. https://doi.org/10.1080/17461391.2015.1042527.
4. Yi Q, Ruano MÁG, Liu H, Sampaio J. Variation of match statistics and football teams' match performance in the group stage of the EUFA Champions league from 2010 to 2017. Kinesiology. 2019;51(2):170–81. https://doi.org/10.26582/k.51.2.4.
5. Bangsbo J, Mohr M, Krustrup P. Physical and metabolic demands of training and match-play in the elite football player. J Sports Sci. 2006;24(7):665–74. https://doi.org/10.1080/02640410500482529.
6. Aslan A, Acikada C, Güvenç A, Gören H, Hazir T, Ozkara A. Metabolic demands of match performance in young soccer players. J Sports Sci Med. 2012;11(1):170–9.
7. Carling C, Le Gall F, Dupont G. Analysis of repeated high-intensity running performance in professional soccer. J Sports Sci. 2012;30(4):325–36. https://doi.org/10.1080/02640414.2011.652655.
8. Serpiello FR, Duthie GM, Moran C, Kovacevic D, Selimi E, Varley MC. The occurrence of repeated high acceleration ability (RHAA) in elite youth football. Int J Sports Med. 2018;39(7):502–7. https://doi.org/10.1055/a-0608-4738.
9. Rampinini E, Bosio A, Ferraresi I, Petruolo A, Morelli A, Sassi A. Match-related fatigue in soccer players. Med Sci Sports Exerc. 2011;43(11):2161–70. https://doi.org/10.1249/MSS.0b013e31821e9c5c.
10. Brocherie F, Millet GP, Girard O. Neuro-mechanical and metabolic adjustments to the repeated anaerobic sprint test in professional football players. Eur J Appl Physiol. 2015;115(5):891–903. https://doi.org/10.1007/s00421-014-3070-z.

11. Russell M, Kingsley M. Influence of exercise on skill proficiency in soccer. Sports Med. 2011;41(7):523–39. https://doi.org/10.2165/11589130-000000000-00000.
12. Silva JR, Rumpf MC, Hertzog M, Castagna C, Farooq A, Girard O, et al. Acute and residual soccer match-related fatigue: a systematic review and meta-analysis. Sports Med. 2018;48(3):539–83. https://doi.org/10.1007/s40279-017-0798-8.
13. Torreblanca-Martinez V, Otero-Saborido FM, Gonzalez-Jurado JA. Effects of muscle fatigue induced by countermovement jumps on efficacy parameters of instep ball kicking in soccer. J Appl Biomech. 2017;33(2):105–11. https://doi.org/10.1123/jab.2016-0040.
14. Stevenson EJ, Watson A, Theis S, Holz A, Harper LD, Russell M. A comparison of isomaltulose versus maltodextrin ingestion during soccer-specific exercise. Eur J Appl Physiol. 2017;117(11):2321–33. https://doi.org/10.1007/s00421-017-3719-5.
15. Ferraz R, van den Tillaar R, Marques MC. The effect of fatigue on kicking velocity in soccer players. J Hum Kinet. 2012;35:97–107. https://doi.org/10.2478/v10078-012-0083-8.
16. Russell M, Benton D, Kingsley M. The effects of fatigue on soccer skills performed during a soccer match simulation. Int J Sports Physiol Perform. 2011;6(2):221–33. https://doi.org/10.1123/ijspp.6.2.221.
17. Ali A, Williams C, Nicholas CW, Foskett A. The influence of carbohydrate-electrolyte ingestion on soccer skill performance. Med Sci Sports Exerc. 2007;39(11):1969–76. https://doi.org/10.1249/mss.0b013e31814fb3e3.
18. Currell K, Conway S, Jeukendrup AE. Carbohydrate ingestion improves performance of a new reliable test of soccer performance. Int J Sport Nutr Exerc Metab. 2009;19(1):34–46. https://doi.org/10.1123/ijsnem.19.1.34.
19. Maly T, Sugimoto D, Izovska J, Zahalka F, Mala L. Effect of muscular strength, asymmetries and fatigue on kicking performance in soccer players. Int J Sports Med. 2018;39(4):297–303. https://doi.org/10.1055/s-0043-123648.
20. Gharbi A, Masmoudi L, Chtourou H, Chaari N, Tabka Z. Effects of recovery mode on physiological and psychological responses and performance of specific skills in young soccer players. J Sports Med Phys Fit. 2017;57(12):1590–6. https://doi.org/10.23736/S0022-4707.16.06598-1.
21. Sánchez-Sánchez J, García-Unanue J, Jiménez-Reyes P, Gallardo A, Burillo P, Felipe JL, et al. Influence of the mechanical properties of third-generation artificial turf systems on soccer players' physiological and physical performance and their perceptions. PLoS ONE. 2014;9(10):e111368. https://doi.org/10.1371/journal.pone.0111368.
22. van der Kruk E, Reijne MM. Accuracy of human motion capture systems for sport applications; state-of-the-art review. Eur J Sport Sci. 2018;18(6):806–19. https://doi.org/10.1080/17461391.2018.1463397.
23. Apriantono T, Nunome H, Ikegami Y, Sano S. The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. J Sports Sci. 2006;24(9):951–60. https://doi.org/10.1080/02640410500386050.
24. Carling C, Dupont G. Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play? J Sports Sci. 2011;29(1):63–71. https://doi.org/10.1080/02640414.2010.521945.
25. Serpiello FR, Cox A, Oppici L, Hopkins WG, Varley MC. The Loughborough Soccer Passing Test has impractical criterion validity in elite youth football. Sci Med Football. 2017;1(1):60–4. https://doi.org/10.1080/02640414.2016.1254810.
26. Ré AHN, Cattuzzo TM, Santos FMC, Monteiro CBM. Anthropometric characteristics, field test scores and match-related technical performance in youth indoor soccer players with different playing status. Int J Perform Anal Sport. 2014;14(2):482–92. https://doi.org/10.1080/24748668.2014.11868737.
27. van den Tillaar R, Fuglstad P. Effect of instructions prioritizing speed or accuracy on kinematics and kicking performance in football players. J Mot Behav. 2017;49(4):414–21. https://doi.org/10.1080/00222895.2016.1219311.
28. van den Tillaar R, Ulvik A. Influence of instruction on velocity and accuracy in soccer kicking of experienced soccer players. J Mot Behav. 2014;46(5):287–91. https://doi.org/10.1080/00222895.2014.898609.
29. Navarro M, van der Kamp J, Ranvaud R, Savelsbergh GJ. The mere presence of a goalkeeper affects the accuracy of penalty kicks. J Sports Sci. 2013;31(9):921–9. https://doi.org/10.1080/02640414.2012.762602.
30. Orth D, Davids K, Araujo D, Renshaw I, Passos P. Effects of a defender on run-up velocity and ball speed when crossing a football. Eur J Sport Sci. 2014;14(Suppl 1):S316–23. https://doi.org/10.1080/17461391.2012.696712.
31. Egan CD, Verheul MH, Savelsbergh GJ. Effects of experience on the coordination of internally and externally timed soccer kicks. J Mot Behav. 2007;39(5):423–32. https://doi.org/10.3200/jmbr.39.5.423-432.
32. Nunome H, Lake M, Georgakis A, Stergioulas LK. Impact phase kinematics of instep kicking in soccer. J Sports Sci. 2006;24(1):11–22. https://doi.org/10.1080/02640410400021450.
33. Kellis E, Katis A. Biomechanical characteristics and determinants of instep soccer kick. J Sports Sci Med. 2007;6(2):154–65.
34. Shan G, Zhang X. From 2D leg kinematics to 3D full-body biomechanics-the past, present and future of scientific analysis of maximal instep kick in soccer. Sports Med Arthrosc Rehabil Ther Technol. 2011;3(1):23. https://doi.org/10.1186/1758-2555-3-23.
35. Ali A. Measuring soccer skill performance: a review. Scand J Med Sci Sports. 2011;21(2):170–83. https://doi.org/10.1111/j.1600-0838.2010.01256.x.
36. Young WB, Rath DA. Enhancing foot velocity in football kicking: the role of strength training. J Strength Cond Res. 2011;25(2):561–6. https://doi.org/10.1519/JSC.0b013e3181bf42eb.
37. Amiri-Khorasani M, Ferdinands RED. The acute effect of stretching on the kinematics of instep kicking in soccer. Sports Technol. 2014;7(1–2):69–78. https://doi.org/10.1080/19346182.2014.893348.
38. Beliard S, Cassirame J, Ennequin G. The effects of a calf pump device on second half performance of a simulated soccer match in competitive youth players. J Sports Sci. 2019;37(6):708–16. https://doi.org/10.1080/02640414.2018.1522947.
39. Russell M, Benton D, Kingsley M. Influence of carbohydrate supplementation on skill performance during a soccer match simulation. J Sci Med Sport. 2012;15(4):348–54. https://doi.org/10.1016/j.jsams.2011.12.006.
40. Hammami A, Zois J, Slimani M, Russel M, Bouhlel E. The efficacy and characteristics of warm-up and re-warm-up practices in soccer players: a systematic review. J Sports Med Phys Fit. 2018;58(1–2):135–49. https://doi.org/10.23736/s0022-4707.16.06806-7.
41. Silva LM, Neiva HP, Marques MC, Izquierdo M, Marinho DA. Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: a systematic review. Sports Med. 2018;48(10):2285–99. https://doi.org/10.1007/s40279-018-0958-5.
42. Bizzini M, Impellizzeri FM, Dvorak J, Bortolan L, Schena F, Modena R, et al. Physiological and performance responses to the "FIFA 11+" (part 1): is it an appropriate warm-up? J Sports Sci. 2013;31(13):1481–90. https://doi.org/10.1080/02640414.2013.802922.

43. Nedelec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer: part ii-recovery strategies. Sports Med. 2013;43(1):9–22. https://doi.org/10.1007/s40279-012-0002-0.
44. Nedelec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer: part I—post-match fatigue and time course of recovery. Sports Med. 2012;42(12):997–1015. https://doi.org/10.2165/11635270-000000000-00000.
45. Dupuy O, Douzi W, Theurot D, Bosquet L, Dugué B. An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: a systematic review with meta-analysis. Front Physiol. 2018;9:403. https://doi.org/10.3389/fphys.2018.00403.
46. Russell M, West DJ, Harper LD, Cook CJ, Kilduff LP. Half-time strategies to enhance second-half performance in team-sports players: a review and recommendations. Sports Med. 2015;45(3):353–64. https://doi.org/10.1007/s40279-014-0297-0.
47. Amiri-Khorasani M, Kellis E. Static vs. dynamic acute stretching effect on quadriceps muscle activity during soccer instep kicking. J Hum Kinet. 2013;39:37–47. https://doi.org/10.2478/hukin-2013-0066.
48. Amiri-Khorasani M, Mohammadkazemi R, Sarafrazi S, Riyahi-Malayeri S, Sotoodeh V. Kinematics analyses related to stretch-shortening cycle during soccer instep kicking after different acute stretching. J Strength Cond Res. 2012;26(11):3010–7. https://doi.org/10.1519/jsc.0b013e3182443442.
49. Amiri-Khorasani M. Kinematics analysis: the acute effect of different stretching methods on dynamic range of motion of lower extremity joints during soccer instep kicking. Int J Perform Anal Sport. 2013;13(1):190–9. https://doi.org/10.1080/24748668.2013.11868641.
50. Gelen E. Acute effects of different warm-up methods on sprint, slalom dribbling, and penalty kick performance in soccer players. J Strength Cond Res. 2010;24(4):950–6. https://doi.org/10.1519/JSC.0b013e3181cb703f.
51. Frikha M, Derbel MS, Chaâri N, Gharbi A, Chamari K. Acute effect of stretching modalities on global coordination and kicking accuracy in 12–13 year-old soccer players. Hum Mov Sci. 2017;54:63–72. https://doi.org/10.1016/j.humov.2017.03.008.
52. Towlson C, Midgley AW, Lovell R. Warm-up strategies of professional soccer players: practitioners' perspectives. J Sports Sci. 2013;31(13):1393–401. https://doi.org/10.1080/02640414.2013.792946.
53. Harper LD, Fothergill M, West DJ, Stevenson E, Russell M. Practitioners' perceptions of the soccer extra-time period: implications for future research. PLoS ONE. 2016;11(7):e0157687. https://doi.org/10.1371/journal.pone.0157687.
54. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097.
55. Methley AM, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. BMC Health Serv Res. 2014;14(1):579. https://doi.org/10.1186/s12913-014-0579-0.
56. Harrison PW, James LP, McGuigan MR, Jenkins DG, Kelly VG. Resistance priming to enhance neuromuscular performance in sport: evidence, potential mechanisms and directions for future research. Sports Med. 2019;49(10):1499–514. https://doi.org/10.1007/s40279-019-01136-3.
57. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA. Cochrane handbook for systematic reviews of interventions, version 6.0 [updated July 2019]. The Cochrane Collaboration; 2019. http://www.training.cochrane.org/handbook. Accessed 5 Dec 2019.
58. Review Manager (RevMan) [Computer program]. Version 5.3 ed. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration; 2014.
59. Palucci Vieira LH, Carling C, Barbieri FA, Aquino R, Santiago PRP. Match running performance in young soccer players: a systematic review. Sports Med. 2019;49(2):289–318. https://doi.org/10.1007/s40279-018-01048-8.
60. Armijo-Olivo S, da Costa BR, Cummings GG, Ha C, Fuentes J, Saltaji H, et al. PEDro or Cochrane to assess the quality of clinical trials? A meta-epidemiological study. PLoS ONE. 2015;10(7):e0132634. https://doi.org/10.1371/journal.pone.0132634.
61. Sarmento H, Clemente FM, Araujo D, Davids K, McRobert A, Figueiredo A. What performance analysts need to know about research trends in Association Football (2012–2016): a systematic review. Sports Med. 2018;48(4):799–836. https://doi.org/10.1007/s40279-017-0836-6.
62. Vieira LHP, Cunha SA, Moraes R, Barbieri FA, Aquino R, Oliveira LP, et al. Kicking performance in young U9 to U20 soccer players: assessment of velocity and accuracy simultaneously. Res Q Exerc Sport. 2018;89(2):210–20. https://doi.org/10.1080/02701367.2018.1439569.
63. Berjan Bacvarevic B, Pazin N, Bozic PR, Mirkov D, Kukolj M, Jaric S. Evaluation of a composite test of kicking performance. J Strength Cond Res. 2012;26(7):1945–52. https://doi.org/10.1519/JSC.0b013e318237e79d.
64. Katis A, Amiridis I, Kellis E, Lees A. Recovery of powerful kick biomechanics after intense running fatigue in male and female soccer players. Asian J Sports Med. 2014;5(4):e24013. https://doi.org/10.5812/asjsm.24013.
65. Katis A, Kellis E. Three-dimensional kinematics and ground reaction forces during the instep and outstep soccer kicks in pubertal players. J Sports Sci. 2010;28(11):1233–41. https://doi.org/10.1080/02640414.2010.504781.
66. Levanon J, Dapena J. Comparison of the kinematics of the full-instep and pass kicks in soccer. Med Sci Sports Exerc. 1998;30(6):917–27. https://doi.org/10.1097/00005768-199806000-00022.
67. Barbieri FA, Gobbi LT, Santiago PR, Cunha SA. Performance comparisons of the kicking of stationary and rolling balls in a futsal context. Sports Biomech. 2010;9(1):1–15. https://doi.org/10.1080/14763141003690211.
68. Barbieri FA, Gobbi LT, Santiago PR, Cunha SA. Dominant-non-dominant asymmetry of kicking a stationary and rolling ball in a futsal context. J Sports Sci. 2015;33(13):1411–9. https://doi.org/10.1080/02640414.2014.990490.
69. Neilson P, Jones R. Dynamic soccer ball performance measurement. In: Reilly T, Korkusuz F, editors. Science and football V. London/New York: Routledge; 2005.
70. Peacock J, Garofolini A, Oppici L, Serpiello F, Ball K. Differences in kicking dynamics of futsal and soccer ball. ISBS Proc Arch. 2017;35(1):48.
71. Katis A, Kellis E, Lees A. Age and gender differences in kinematics of powerful instep kicks in soccer. Sports Biomech. 2015;14(3):287–99. https://doi.org/10.1080/14763141.2015.1056221.
72. Kellis E, Katis A, Gissis I. Knee biomechanics of the support leg in soccer kicks from three angles of approach. Med Sci Sports Exerc. 2004;36(6):1017–28. https://doi.org/10.1249/01.mss.0000128147.01979.31.
73. Radman I, Wessner B, Bachl N, Ruzic L, Hackl M, Baca A, et al. Reliability and discriminative ability of a new method for soccer kicking evaluation. PLoS ONE. 2016;11(1):e0147998. https://doi.org/10.1371/journal.pone.0147998.
74. Andersen TB, Dorge HC. The influence of speed of approach and accuracy constraint on the maximal speed of the ball in

soccer kicking. Scand J Med Sci Sports. 2011;21(1):79–84. https://doi.org/10.1111/j.1600-0838.2009.01024.x.
75. Teixeira LA. Kinematics of kicking as a function of different sources of constraint on accuracy. Percept Mot Skills. 1999;88(3):785–9. https://doi.org/10.2466/pms.1999.88.3.785.
76. Shan G, Westerhoff P. Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. Sports Biomech. 2005;4(1):59–72. https://doi.org/10.1080/14763140508522852.
77. Katis A, Giannadakis E, Kannas T, Amiridis I, Kellis E, Lees A. Mechanisms that influence accuracy of the soccer kick. J Electromyogr Kinesiol. 2013;23(1):125–31. https://doi.org/10.1016/j.jelekin.2012.08.020.
78. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hilsdale: Lawrence Earlbaum Associates; 1988.
79. Bleakley CM, Costello JT, Glasgow PD. Should athletes return to sport after applying ice? A systematic review of the effect of local cooling on functional performance. Sports Med. 2012;42(1):69–87. https://doi.org/10.2165/11595970-000000000-00000.
80. Fox JL, Scanlan AT, Stanton R, Sargent C. Insufficient sleep in young athletes? Causes, consequences, and potential treatments. Sports Med. 2020;50(3):461–70. https://doi.org/10.1007/s40279-019-01220-8.
81. Araújo CG, Scharhag J. Athlete: a working definition for medical and health sciences research. Scand J Med Sci Sports. 2016;26(1):4–7. https://doi.org/10.1111/sms.12632.
82. Chaabene H, Prieske O, Moran J, Negra Y, Attia A, Granacher U. Effects of resistance training on change-of-direction speed in youth and young physically active and athletic adults: a systematic review with meta-analysis. Sports Med. 2020;50(8):1483–99. https://doi.org/10.1007/s40279-020-01293-w.
83. van Tulder M, Furlan A, Bombardier C, Bouter L, Group tEBotC-CBR. Updated method guidelines for systematic reviews in the cochrane collaboration back review group. Spine (Phila Pa 1976). 2003;28(12):1290–9. https://doi.org/10.1097/01.Brs.0000065484.95996.Af.
84. Fanchini M, Steendahl IB, Impellizzeri FM, Pruna R, Dupont G, Coutts AJ, et al. Exercise-based strategies to prevent muscle injury in elite footballers: a systematic review and best evidence synthesis. Sports Med. 2020;50(9):1653–66. https://doi.org/10.1007/s40279-020-01282-z.
85. Abbey EL, Rankin JW. Effect of ingesting a honey-sweetened beverage on soccer performance and exercise-induced cytokine response. Int J Sport Nutr Exerc Metab. 2009;19(6):659–72. https://doi.org/10.1123/ijsnem.19.6.659.
86. Abt G, Zhou S, Weatherby R. The effect of a high-carbohydrate diet on the skill performance of midfield soccer players after intermittent treadmill exercise. J Sci Med Sport. 1998;1(4):203–12. https://doi.org/10.1016/s1440-2440(09)60003-7.
87. Amiri-Khorasani M, Osman N, Yusof A. Kinematics analysis: number of trials necessary to achieve performance stability during soccer instep kicking. J Hum Kinet. 2010;23(1):15–20. https://doi.org/10.2478/v10078-010-0002-9.
88. Amiri-Khorasani M, Abu Osman NA, Yusof A. Electromyography assessments of the vastus medialis muscle during soccer instep kicking between dynamic and static stretching. J Hum Kinet. 2010;24(1):35–41. https://doi.org/10.2478/v10078-010-0017-2.
89. Amiri-Khorasani M, Abu Osam NA, Yusof A. Biomechanical responses of thigh and lower leg during 10 consecutive soccer instep kicks. J Strength Cond Res. 2011;25(4):1177–81. https://doi.org/10.1519/JSC.0b013e3181d6508c.
90. Amiri-Khorasani M, Abu Osman NA, Yusof A. Acute effect of static and dynamic stretching on hip dynamic range of motion during instep kicking in professional soccer players. J Strength Cond Res. 2011;25(6):1647–52. https://doi.org/10.1519/JSC.0b013e3181db9f41.
91. Cariolo A, Del Coso J, Argudo FM, Borges-Hernandez PJ. Effects of rehydration on the physical and technical condition in soccer players. Apunts Medicina de l'Esport. 2018;54(201):5–11. https://doi.org/10.1016/j.apunts.2018.09.004.
92. Deutschmann KC, Jones AD, Korporaal CM. A non-randomised experimental feasibility study into the immediate effect of three different spinal manipulative protocols on kicking speed performance in soccer players. Chiropr Man Ther. 2015;23(1):1. https://doi.org/10.1186/s12998-014-0046-3.
93. Draganidis D, Chatzinikolaou A, Jamurtas AZ, Barbero JC, Tsoukas D, Theodorou AS, et al. The time-frame of acute resistance exercise effects on football skill performance: the impact of exercise intensity. J Sports Sci. 2013;31(7):714–22. https://doi.org/10.1080/02640414.2012.746725.
94. Ferraz R, van den Tillar R, Marques MC. The influence of different exercise intensities on kicking accuracy and velocity in soccer players. J Sport Health Sci. 2017;6(4):462–7. https://doi.org/10.1016/j.jshs.2015.10.001.
95. Ferraz R, Van Den Tillaar R, Ferraz S, Santos A, Mendes R, Marinho DA, et al. A pilot study on the influence of fatigue on kicking velocity in the soccer players. J Phys Educ Sport. 2011;11(2):178–81.
96. Ferraz RMP, van den Tillaar R, Pereira A, Marques MC. The effect of fatigue and duration knowledge of exercise on kicking performance in soccer players. J Sport Health Sci. 2019;8(6):567–73. https://doi.org/10.1016/j.jshs.2016.02.001.
97. Greig M. Intermittent treadmill running induces kinematic compensations to maintain soccer kick foot speed despite no change in knee extensor strength. J Appl Biomech. 2018;34(4):278–83. https://doi.org/10.1123/jab.2017-0017.
98. Hasan H, Davids K, Chow JY, Kerr G. Compression and texture in socks enhance football kicking performance. Hum Mov Sci. 2016;48:102–11. https://doi.org/10.1016/j.humov.2016.04.008.
99. Hasan H, Davids K, Chow JY, Kerr G. Changes in organisation of instep kicking as a function of wearing compression and textured materials. Eur J Sport Sci. 2017;17(3):294–302. https://doi.org/10.1080/17461391.2016.1241829.
100. Juarez D, de Subijana CL, Mallo J, Navarro E. Acute effects of endurance exercise on jumping and kicking performance in top-class young soccer players. Eur J Sport Sci. 2011;11(3):191–6. https://doi.org/10.1080/17461391.2010.500335.
101. Katis A, Kellis E, Lees A. Bilateral leg differences in soccer kick kinematics following exhaustive running fatigue. Asian J Sports Med. 2017;8(2):e33680. https://doi.org/10.5812/asjsm.33680.
102. Kellis E, Katis A, Vrabas IS. Effects of an intermittent exercise fatigue protocol on biomechanics of soccer kick performance. Scand J Med Sci Sports. 2006;16(5):334–44.
103. Masmoudi L, Gharbi A, Chtourou H, Souissi N. Effect of time of day on soccer specific skills in children: psychological and physiological responses. Biol Rhythm Res. 2016;47(1):59–68. https://doi.org/10.1080/09291016.2015.1073888.
104. McMorris T, Sproule J, Draper S, Child R. Performance of a psychomotor skill following rest, exercise at the plasma epinephrine threshold and maximal intensity exercise. Percept Mot Skills. 2000;91(2):553–62. https://doi.org/10.2466/pms.2000.91.2.553.
105. McMorris T, Swain J, Lauder M, Smith N, Kelly J. Warm-up prior to undertaking a dynamic psychomotor task: does it aid performance? J Sports Med Phys Fit. 2006;46(2):328–34.
106. Muller C, Brandes M. Effect of kinesiotape applications on ball velocity and accuracy in amateur soccer and handball. J Hum Kinet. 2015;49(1):119–29. https://doi.org/10.1515/hukin-2015-0114.
107. Owen JA, Kehoe SJ, Oliver SJ. Influence of fluid intake on soccer performance in a temperate environment. J Sports

Sci. 2013;31(1):1–10. https://doi.org/10.1080/02640414.2012.720701.
108. Ozturk M, Gelen E. The acute effects of specific preconditioning activities on penalty kick performance in soccer players. Anthropologist. 2015;22(3):679–86.
109. Pallesen S, Gundersen HS, Kristoffersen M, Bjorvatn B, Thun E, Harris A. The effects of sleep deprivation on soccer skills. Percept Mot Skills. 2017;124(4):812–29. https://doi.org/10.1177/0031512517707412.
110. Radman I, Wessner B, Bachl N, Ruzic L, Hackl M, Prpic T, et al. The acute effects of graded physiological strain on soccer kicking performance: a randomized, controlled cross-over study. Eur J Appl Physiol. 2016;116(2):373–82. https://doi.org/10.1007/s00421-015-3293-7.
111. Sasadai J, Urabe Y, Maeda N, Shinohara H, Fujii E. The effect of ankle taping to restrict plantar flexion on ball and foot velocity during an instep kick in soccer. J Sport Rehabil. 2015;24(3):261–7. https://doi.org/10.1123/jsr.2013-0156.
112. Stone KJ, Oliver JL. The effect of 45 minutes of soccer-specific exercise on the performance of soccer skills. Int J Sports Physiol Perform. 2009;4(2):163–75. https://doi.org/10.1123/ijspp.4.2.163.
113. Zemková E, Hamar D. The effect of soccer match induced fatigue on neuromuscular performance. Kinesiology. 2009;41(2):195–202.
114. Gaspar A, Santos S, Coutinho D. Acute effects of differential learning on football kicking performance and in countermovement jump. PLoS ONE. 2019;14(10):e0224280. https://doi.org/10.1371/journal.pone.0224280.
115. Otten R, Stam S, Langhout R, Weir A, Tak I. The effect of compression shorts on pain and performance in male football players with groin pain—a double blinded randomized controlled trial. Phys Ther Sport. 2019;38:87–95. https://doi.org/10.1016/j.ptsp.2019.04.013.
116. Izquierdo JM, De Benito AM, Gorka A, Guevara G, Redondo JC. Influence of competition on performance factors in under-19 soccer players at national league level. PLoS ONE. 2020;15(3):e0230068. https://doi.org/10.1371/journal.pone.0230068.
117. Kaviani M, Chilibeck PD, Gall S, Jochim J, Zello GA. The effects of low- and high-glycemic index sport nutrition bars on metabolism and performance in recreational soccer players. Nutrients. 2020;12(4):982. https://doi.org/10.3390/nu12040982.
118. Paillard T. Effects of general and local fatigue on postural control: a review. Neurosci Biobehav Rev. 2012;36(1):162–76. https://doi.org/10.1016/j.neubiorev.2011.05.009.
119. Chamari K, Padulo J. "Aerobic" and "Anaerobic" terms used in exercise physiology: a critical terminology reflection. Sports Med Open. 2015;1(1):9. https://doi.org/10.1186/s40798-015-0012-1.
120. Jones AM, Vanhatalo A. The "critical power" concept: applications to sports performance with a focus on intermittent high-intensity exercise. Sports Med. 2017;47(Suppl 1):65–78. https://doi.org/10.1007/s40279-017-0688-0.
121. Boullosa D, Del Rosso S, Behm DG, Foster C. Post-activation potentiation (PAP) in endurance sports: a review. Eur J Sport Sci. 2018;18(5):595–610. https://doi.org/10.1080/17461391.2018.1438519.
122. Nicholas CW, Nuttall FE, Williams C. The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. J Sports Sci. 2000;18(2):97–104. https://doi.org/10.1080/026404100365162.
123. Small K, McNaughton LR, Greig M, Lohkamp M, Lovell R. Soccer fatigue, sprinting and hamstring injury risk. Int J Sports Med. 2009;30(8):573–8. https://doi.org/10.1055/s-0029-1202822.
124. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo intermittent recovery test: a useful tool for evaluation of physical performance in intermittent sports. Sports Med. 2008;38(1):37–51. https://doi.org/10.2165/00007256-200838010-00004.
125. Russell M, Rees G, Benton D, Kingsley M. An exercise protocol that replicates soccer match-play. Int J Sports Med. 2011;32(7):511–8. https://doi.org/10.1055/s-0031-1273742.
126. Greig MP, McNaughton LR, Lovell RJ. Physiological and mechanical response to soccer-specific intermittent activity and steady-state activity. Res Sports Med. 2006;14(1):29–52. https://doi.org/10.1080/15438620500528257.
127. Palucci Vieira L, Barbieri F, Kellis E, Oliveira LP, Aquino R, Cunha S, et al. Organisation of instep kicking in young U11 to U20 soccer players. Sci Med Football. 2020. https://doi.org/10.1080/24733938.2020.1807043 (**Publish Ahead of Print**).
128. Knudson D. Top cited research over fifteen years in Sports Biomechanics. Sports Biomech. 2020;19(6):808–16. https://doi.org/10.1080/14763141.2018.1518478.
129. Fitts PM. The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol. 1954;47(6):381–91.
130. Rathke A. An examination of expected goals and shot efficiency in soccer. J Hum Sport Exerc. 2017;12(2):514–29. https://doi.org/10.14198/jhse.2017.12.Proc2.05.
131. Schulze E, Mendes B, Maurício N, Furtado B, Cesário N, Carriço S, et al. Effects of positional variables on shooting outcome in elite football. Sci Med Football. 2018;2(2):93–100. https://doi.org/10.1080/24733938.2017.1383628.
132. Scurr J, Hall B. The effects of approach angle on penalty kicking accuracy and kick kinematics with recreational soccer players. J Sports Sci Med. 2009;8(2):230–4.
133. Navia JA, van der Kamp J, Avilés C, Aceituno J. Self-control in aiming supports coping with psychological pressure in soccer penalty kicks. Front Psychol. 2019;10:1438. https://doi.org/10.3389/fpsyg.2019.01438.
134. De Witt JK, Hinrichs RN. Mechanical factors associated with the development of high ball velocity during an instep soccer kick. Sports Biomech. 2012;11(3):382–90. https://doi.org/10.1080/14763141.2012.661757.
135. Hunter AH, Angilletta MJ Jr, Wilson RS. Behaviors of shooter and goalkeeper interact to determine the outcome of soccer penalties. Scand J Med Sci Sports. 2018;28(12):2751–9. https://doi.org/10.1111/sms.13276.
136. Hughes M, Wells J. Analysis of penalties taken in shootouts. Int J Perform Anal Sport. 2002;2(1):55–72. https://doi.org/10.1080/24748668.2002.11868261.
137. Dichiera A, Webster KE, Kuilboer L, Morris ME, Bach TM, Feller JA. Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. J Sci Med Sport. 2006;9(4):292–8. https://doi.org/10.1016/j.jsams.2006.06.007.
138. Ishii H, Yanagiya T, Naito H, Katamoto S, Maruyama T. Numerical study of ball behavior in side-foot soccer kick based on impact dynamic theory. J Biomech. 2009;42(16):2712–20. https://doi.org/10.1016/j.jbiomech.2009.08.025.
139. Andersen TB, Dörge T. Collisions in soccer kicking. Sports Eng. 1999;2(2):121–5. https://doi.org/10.1046/j.1460-2687.1999.00015.x.
140. Hadlow SM, Pinder RA, Sayers MGL. Influence of football size on kicking performance in youth Australian rules footballers. J Sports Sci. 2017;35(18):1808–16. https://doi.org/10.1080/02640414.2016.1239023.
141. Andersen TB, Krustrup P, Bendiksen M, Orntoft CO, Randers MB, Pettersen SA. Kicking velocity and effect on match performance when using a smaller, lighter ball in women's football. Int J Sports Med. 2016;37(12):966–72. https://doi.org/10.1055/s-0042-109542.

142. Sedano Campo S, Vaeyens R, Philippaerts RM, Redondo JC, de Benito AM, Cuadrado G. Effects of lower-limb plyometric training on body composition, explosive strength, and kicking speed in female soccer players. J Strength Cond Res. 2009;23(6):1714–22. https://doi.org/10.1519/JSC.0b013e3181b3f537.
143. Smith L, Kensrud J. Field and laboratory measurements of softball player swing speed and bat performance. Sports Eng. 2014;17(2):75–82. https://doi.org/10.1007/s12283-013-0126-y.
144. Nunome H, Ikegami Y, editors. Kinematics of soccer instep kicking: a comparison of two-dimensional and three-dimensional analysis. ISBS Proc Arch. 2006;MOB2–3:1–4.
145. Palucci Vieira LH, De Andrade VL, Aquino RL, Moraes R, Barbieri FA, Cunha SA, et al. Construct validity of tests that measure kick performance for young soccer players based on cluster analysis: exploring the relationship between coaches rating and actual measures. J Sports Med Phys Fit. 2017;57(12):1613–22. https://doi.org/10.23736/S0022-4707.16.06863-8.
146. Asai T, Carré M, Akatsuka T, Haake S. The curve kick of a football I: impact with the foot. Sports Eng. 2002;5(4):183–92. https://doi.org/10.1046/j.1460-2687.2002.00108.x.
147. Deschamps K, Staes F, Roosen P, Nobels F, Desloovere K, Bruyninckx H, et al. Body of evidence supporting the clinical use of 3D multisegment foot models: a systematic review. Gait Posture. 2011;33(3):338–49. https://doi.org/10.1016/j.gaitpost.2010.12.018.
148. Knudson D, Bahamonde R. Effect of endpoint conditions on position and velocity near impact in tennis. J Sports Sci. 2001;19(11):839–44. https://doi.org/10.1080/026404101753113787.
149. Augustus S, Amca AM, Hudson PE, Smith N. Improved accuracy of biomechanical motion data obtained during impacts using a time-frequency low-pass filter. J Biomech. 2020;101:109639. https://doi.org/10.1016/j.jbiomech.2020.109639.
150. Russell M, Benton D, Kingsley M. Reliability and construct validity of soccer skills tests that measure passing, shooting, and dribbling. J Sports Sci. 2010;28(13):1399–408. https://doi.org/10.1080/02640414.2010.511247.
151. Padrón-Cabo A, Rey E, Pérez-Ferreirós A, Kalén A. Test-retest reliability of skill tests in the F-MARC battery for youth soccer players. Percept Mot Skills. 2019;126(5):1006–23. https://doi.org/10.1177/0031512519866038.
152. Bacurau RFP, Monteiro GA, Ugrinowitsch C, Tricoli V, Cabral LF, Aoki MS. Acute effect of a ballistic and a static stretching exercise bout on flexibility and maximal strength. J Strength Cond Res. 2009;23(1):304–8. https://doi.org/10.1519/JSC.0b013e3181874d55.
153. Shellock FG, Prentice WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med. 1985;2(4):267–78. https://doi.org/10.2165/00007256-198502040-00004.
154. Knudson D, Bennett K, Corn R, Leick D, Smith C. Acute effects of stretching are not evident in the kinematics of the vertical jump. J Strength Cond Res. 2001;15(1):98–101.
155. Cramer JT, Housh TJ, Weir JP, Johnson GO, Coburn JW, Beck TW. The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. Eur J Appl Physiol. 2005;93(5–6):530–9. https://doi.org/10.1007/s00421-004-1199-x.
156. Behm DG, Button DC, Butt JC. Factors affecting force loss with prolonged stretching. Can J Appl Physiol. 2001;26(3):261–72.
157. Cramer JT, Beck TW, Housh TJ, Massey LL, Marek SM, Danglemeier S, et al. Acute effects of static stretching on characteristics of the isokinetic angle—torque relationship, surface electromyography, and mechanomyography. J Sports Sci. 2007;25(6):687–98. https://doi.org/10.1080/02640410600818416.
158. Oliveira LP, Vieira LHP, Aquino R, Manechini JPV, Santiago PRP, Puggina EF. Acute effects of active, ballistic, passive, and proprioceptive neuromuscular facilitation stretching on sprint and vertical jump performance in trained young soccer players. J Strength Cond Res. 2018;32(8):2199–208. https://doi.org/10.1519/jsc.0000000000002298.
159. Gabbett TJ, Sheppard JM, Pritchard-Peschek KR, Leveritt MD, Aldred MJ. Influence of closed skill and open skill warm-ups on the performance of speed, change of direction speed, vertical jump, and reactive agility in team sport athletes. J Strength Cond Res. 2008;22(5):1413–5. https://doi.org/10.1519/JSC.0b013e3181739ecd.
160. Little T, Williams AG. Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. J Strength Cond Res. 2006;20(1):203–7. https://doi.org/10.1519/r-16944.1.
161. Fradkin AJ, Zazryn TR, Smoliga JM. Effects of warming-up on physical performance: a systematic review with meta-analysis. J Strength Cond Res. 2010;24(1):140–8. https://doi.org/10.1519/JSC.0b013e3181c643a0.
162. Speirs DE, Bennett MA, Finn CV, Turner AP. Unilateral vs. bilateral squat training for strength, sprints, and agility in academy rugby players. J Strength Cond Res. 2016;30(2):386–92. https://doi.org/10.1519/jsc.0000000000001096.
163. Bishop D. Warm up II: performance changes following active warm up and how to structure the warm up. Sports Med. 2003;33(7):483–98. https://doi.org/10.2165/00007256-200333070-00002.
164. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM, et al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. J Strength Cond Res. 2013;27(3):854–9. https://doi.org/10.1519/JSC.0b013e31825c2bdb.
165. Castagna C, Francini L, Povoas SCA, D'Ottavio S. Long-sprint abilities in soccer: ball versus running drills. Int J Sports Physiol Perform. 2017;12(9):1256–63. https://doi.org/10.1123/ijspp.2016-0565.
166. Zagatto AM, Papoti M, Da Silva A, Barbieri RA, Campos EZ, Ferreira EC, et al. The Hoff circuit test is more specific than an incremental treadmill test to assess endurance with the ball in youth soccer players. Biol Sport. 2016;33(3):263–8. https://doi.org/10.5604/20831862.1201913.
167. Milioni F, Vieira LH, Barbieri RA, Zagatto AM, Nordsborg NB, Barbieri FA, et al. Futsal match-related fatigue affects running performance and neuromuscular parameters but not finishing kick speed or accuracy. Front Physiol. 2016;7:518. https://doi.org/10.3389/fphys.2016.00518.
168. Aquino R, Carling C, Maia J, Palucci Vieira LH, Wilson RS, Smith N, et al. Relationships between running demands in soccer match-play, anthropometric, and physical fitness characteristics: a systematic review. Int J Perform Anal Sport. 2020;20(3):534–55. https://doi.org/10.1080/24748668.2020.1746555.
169. Paul DJ, Nassis GP. Physical fitness testing in youth soccer: issues and considerations regarding reliability, validity and sensitivity. Pediatr Exerc Sci. 2015;27(3):301–13. https://doi.org/10.1123/mc.2014-0085.
170. Rampinini E, Bishop D, Marcora SM, Ferrari Bravo D, Sassi R, Impellizzeri FM. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int J Sports Med. 2007;28(3):228–35. https://doi.org/10.1055/s-2006-924340.
171. Delaney JA, Thornton HR, Rowell AE, Dascombe BJ, Aughey RJ, Duthie GM. Modelling the decrement in running intensity within professional soccer players. Sci Med Football.

2018;2(2):86–92. https://doi.org/10.1080/24733938.2017.1383623.

172. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. Int J Sports Med. 2014;35(13):1095–100. https://doi.org/10.1055/s-0034-1375695.
173. Hunter AH, Angilletta MJ Jr, Pavlic T, Lichtwark G, Wilson RS. Modeling the two-dimensional accuracy of soccer kicks. J Biomech. 2018;72:159–66. https://doi.org/10.1016/j.jbiomech.2018.03.003.
174. Rodacki AL, Fowler NE, Bennett SJ. Vertical jump coordination: fatigue effects. Med Sci Sports Exerc. 2002;34(1):105–16. https://doi.org/10.1097/00005768-200201000-00017.
175. Rodacki AL, Fowler NE, Bennett SJ. Multi-segment coordination: fatigue effects. Med Sci Sports Exerc. 2001;33(7):1157–67. https://doi.org/10.1097/00005768-200107000-00013.
176. Vieira LH, de Souza SF, de Andrade VL, de Paula OL, Mariano FP, Santana JE, et al. Kicking performance and muscular strength parameters with dominant and non-dominant lower limbs in Brazilian elite professional futsal players. J Appl Biomech. 2016;32(6):578–85. https://doi.org/10.1123/jab.2016-0125.
177. Mohr M, Krustrup P, Bangsbo J. Fatigue in soccer: a brief review. J Sports Sci. 2005;23(6):593–9. https://doi.org/10.1080/02640410400021286.
178. Mohr M, Krustrup P, Nybo L, Nielsen JJ, Bangsbo J. Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time. Scand J Med Sci Sports. 2004;14(3):156–62. https://doi.org/10.1111/j.1600-0838.2004.00349.x.
179. Lovell R, Midgley A, Barrett S, Carter D, Small K. Effects of different half-time strategies on second half soccer-specific speed, power and dynamic strength. Scand J Med Sci Sports. 2013;23(1):105–13. https://doi.org/10.1111/j.1600-0838.2011.01353.x.
180. Maly T, Zahalka F, Mala L, Teplan J. Profile, correlation and structure of speed in youth elite soccer players. J Hum Kinet. 2014;40:149–59. https://doi.org/10.2478/hukin-2014-0017.
181. Barnett A. Using recovery modalities between training sessions in elite athletes: does it help? Sports Med. 2006;36(9):781–96. https://doi.org/10.2165/00007256-200636090-00005.
182. Hills SP, Russell M. Carbohydrates for soccer: a focus on skilled actions and half-time practices. Nutrients. 2018;10(1):22.
183. Krustrup P, Ørtenblad N, Nielsen J, Nybo L, Gunnarsson TP, Iaia FM, et al. Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game. Eur J Appl Physiol. 2011;111(12):2987–95. https://doi.org/10.1007/s00421-011-1919-y.
184. Nybo L. CNS fatigue and prolonged exercise: effect of glucose supplementation. Med Sci Sports Exerc. 2003;35(4):589–94. https://doi.org/10.1249/01.mss.0000058433.85789.66.
185. Jeukendrup A. A step towards personalized sports nutrition: carbohydrate intake during exercise. Sports Med. 2014;44(Suppl 1):S25–33. https://doi.org/10.1007/s40279-014-0148-z.
186. Pluta A, Williams CC, Binsted G, Hecker KG, Krigolson OE. Chasing the zone: reduced beta power predicts baseball batting performance. Neurosci Lett. 2018;686:150–4. https://doi.org/10.1016/j.neulet.2018.09.004.
187. Collins D, Powell G, Davies I. Cerebral activity prior to motion task performance: an electroencephalographic study. J Sports Sci. 1991;9(3):313–24. https://doi.org/10.1080/02640419108729892.
188. Bongers CC, Thijssen DH, Veltmeijer MT, Hopman MT, Eijsvogels TM. Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. Br J Sports Med. 2015;49(6):377–84. https://doi.org/10.1136/bjsports-2013-092928.
189. Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. Sports Med. 2015;45(2):161–86. https://doi.org/10.1007/s40279-014-0260-0.
190. Bonnar D, Bartel K, Kakoschke N, Lang C. Sleep interventions designed to improve athletic performance and recovery: a systematic review of current approaches. Sports Med. 2018;48(3):683–703. https://doi.org/10.1007/s40279-017-0832-x.
191. Lastella M, Lovell GP, Sargent C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. Eur J Sport Sci. 2014;14(Suppl 1):S123–30. https://doi.org/10.1080/17461391.2012.660505.
192. Buchheit M. Houston, we still have a problem. Int J Sports Physiol Perform. 2017;12(8):1111–4. https://doi.org/10.1123/ijspp.2017-0422.
193. Gabbett TJ, Whyte DG, Hartwig TB, Wescombe H, Naughton GA. The relationship between workloads, physical performance, injury and illness in adolescent male football players. Sports Med. 2014;44(7):989–1003. https://doi.org/10.1007/s40279-014-0179-5.
194. Amiri-Khorasani M, Osman NAA, Yusof A. Biomechanical responds of instep kick between different positions in professional soccer players. J Hum Kinet. 2009;22(1):21–7. https://doi.org/10.2478/v10078-009-0019-0.
195. Carling C, Bloomfield J, Nelsen L, Reilly T. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. Sports Med. 2008;38(10):839–62. https://doi.org/10.2165/00007256-200838100-00004.
196. Gomes TN, Katzmarzyk PT, Pereira S, Thuany M, Standage M, Maia J. A systematic review of children's physical activity patterns: concept, operational definitions, instruments, statistical analyses, and health implications. Int J Environ Res Public Health. 2020;17(16):5837. https://doi.org/10.3390/ijerph17165837.
197. MacMillan GCS, Batterham AM, Chesterton P, Gregson W, Lolli L, Weston M, Atkinson G. Variability in the study quality appraisals reported in systematic reviews on the acute:chronic workload ratio and injury risk. Sports Med. 2020;50(11):2065–7. https://doi.org/10.1007/s40279-020-01333-5.
198. Torreblanca-Martínez V, Nevado-Garrosa F, Otero-Saborido FM, Gonzalez-Jurado JA. Effects of fatigue induced by repeated-sprint on kicking accuracy and velocity in female soccer players. PLoS ONE. 2020;15(1):e0227214. https://doi.org/10.1371/journal.pone.0227214.

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