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Review

The demands of the extra-time period of soccer: A systematic review

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Abstract

Objective: Soccer match-play is typically contested over 90 min; however, in some cup and tournament scenarios, when matches are tied, they proceed to an additional 30 min, which is termed "extra-time" (ET). This systematic review sought to appraise the literature available on 120-min of soccer-specific exercise, with a view to identifying practical recommendations and future research opportunities.
Methods: The review was conducted according to the PRISMA guidelines. Independent researchers performed a systematic search of PubMed, CINAHL and PsycINFO in May 2019, with the following keywords entered in various combinations: "soccer", "football", "extra-time", "extra time", "120 minutes", "120 min" "additional 30 minutes", and "additional 30 min."
Results: The search yielded an initial 73 articles. Following the screening process, 11 articles were accepted for analyses. Articles were subsequently organized into the following 5 categories: movement demands of ET, performance responses to ET, physiological and neuromuscular response during ET, nutritional interventions, and recovery and ET. The results highlighted that during competitive match-play, players cover 5%−12% less distance relative to match duration (i.e., meters per minute) during ET compared to the preceding 90 min. Reductions in technical performance (i.e., shot speed, number of passes and dribbles) were also observed during ET. Additionally, carbohydrate provision may attenuate and improve dribbling performance during ET. Moreover, objective and subjective measures of recovery may be further compromised following ET when compared to 90 min.
Conclusion: Additional investigations are warranted to further substantiate these findings and identify interventions to improve performance during ET.

Keywords: Movement demands; Neuromuscular fatigue; Nutritional intervention; Performance; Physiology

1. Introduction

Soccer is a self-paced, irregular, multidirectional, and intermittent team sport typically contested over two 45-min halves and interspersed by a ~15 min half-time rest interval. The more rigorous soccer investigations have shown that the physical response of players is progressively reduced across 90 min of match-play.[1−4] The mechanisms for such responses are likely peripheral and central in origin,[5−7] although less is known regarding the fatigue profile of players during extra-time (ET). When knockout-phase matches are tied during tournaments and an outright winner is required, an ET period of match-play commences 5 min after the 90-min match and consists of 15-min halves separated by a 2-min break during which teams typically swap ends of the pitch.

ET was introduced as far back as 1897 in the English Football Association's rules of play and has been included in the Fédération Internationale de Football Association (FIFA) set of rules for a number of years. Amid the chaos of war in the 1940s, new formats of ET were trialed when there was a tie at the end of the 90-min match. For instance, matches that were level following 90 min of match-play during the Football League War Cup were decided according to the team that had the higher league position. Additionally, during the League South Cup in 1942−1943, an alternative method was piloted: the first team to score or be awarded a corner after 20 min of ET would win the match. However, following much

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controversy, this was soon reconsidered. Consequently, a "next goal wins" agreement was piloted during the 1946 Division Three North Cup. However, one particular match lasted 203 min, but the match remained tied and was thus "postponed". In 1993, the "golden goal" rule (first team to score in ET wins the game) and "silver goal" rule (the team leading at the end of the first 15-min period wins the match) were introduced by soccer's governing bodies. However, in late 2004 these alternative formats of ET were abolished, and the current regulations stipulate that a full 30-min ET period be played. If an outcome is not decided during this time frame, then a penalty shootout determines the winning team.[8,9]

In recent years, ET has increasingly become a deciding factor in determining the outcome of cup competitions and tournaments. Since the 1986 FIFA World Cup competition, 33% of knockout matches have required ET. At the 2014 tournament, 50% of knockout matches required ET compared to 25% of matches at the 2002 and 2010 World Cup competitions, as well as 38% of matches at the 2006 World Cup tournament. More recently, 31% of knockout matches played at the 2018 FIFA World Cup proceeded to ET, with just one of the match outcomes decided during this period. Interestingly, in the 2016 Union of European Football Associations championships, Portugal played ~60 min more match-time on their route to the final (which also proceeded to ET) than counterparts France.

When considering that the fatigue response associated with 90 min of soccer has been well documented[10] and that fatigue-induced changes are sufficient to impair performance and increase injury-risk,[6,11–13] it could be postulated that the potential of additional physical loads being placed on players during ET could further result in reduced performance and an increased risk of injury. Increasing knowledge in relation to the physical demands associated with ET periods may also be useful to ascertain whether there is a need to modify recovery strategies, manipulate nutritional intake and adapt training prescriptions for the purpose of reducing injury risk following ET and improving physical performance during ET. In addition, evidence suggests that fatigue has deleterious effects on aspects of technical performance,[14] which have been shown previously to correlate with team success.[15] Therefore, it may be desirable to determine the extent to which technical/skill actions are further affected by the additional exercise duration and potential fatigue imposed by ET. Furthermore, empirical evidence suggests that 63% of the soccer practitioners sampled (identified as working at professional clubs) agreed that ET was an important time period in determining tournament success.[16] Consequently, organizing and appraising the ET literature is needed to analyze the scientific and empirical research findings that are currently pertinent for professional soccer practitioners to use in relation to ET.

This review takes a systematic approach to organizing the ET literature, which is warranted given that, to date, and to the best of our knowledge, no systematic reviews have been published on the ET period. Therefore, this systematic review aims to synthesize the literature associated with 120 min of soccer-specific activity, identifying the key themes of studies on this topic, characterising the methodologies employed, and informing researchers about the evolving knowledge of ET. In addition, the current review will compare responses during the ET period to the preceding 90 min of match-play with the intention of informing practice and identifying future research opportunities.

2. Methods

2.1. *Search strategy: Databases, screening process, and eligibility criteria*

A review of the literature was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses PRISMA guidelines Keywords were entered in various combinations that related to the topic ("soccer" OR "football"), AND variations of terms for ET ("Extra-time" OR "Extra time" OR "Extratime" OR "120 minutes" OR "120 min"). During May 2019, the following databases were searched: PubMed (1950−present), CINAHL (1981−present), and PsycINFO (1806− present). In addition, we conducted manual searches from the reference lists of the published manuscripts retained. Filters included original publications for which full English texts were available. Any potential articles were retrieved after the titles and abstracts were scanned. Once the screening of titles and abstracts was carried out and the removal of duplicates was completed, a systematic review strategy was employed to assess full texts. The inclusion criteria for these studies were as follows: (1) the study included relevant ET data, (2) participants were male soccer players ≥18 years old, (3) the ET period comprised a full 30-min duration, and (4) the study was written in English. Articles were excluded if they (1) used soccer-specific exercise <120 min in duration, (2) involved participants who had no previous soccer experience, (3) lacked an explicit description of their methodological processes, (4) took the form of a review article, (5) included female participants, or (6) could be classified as grey literature.

2.2. *Data extraction*

Two independent reviewers (AF and LDC) independently carried out the screening process. However, any disputes between the 2 reviewers regarding the inclusion of articles were discussed with and ultimately adjudicated by the senior author (LDH). The 2 reviewers also extracted data from all articles, and, where appropriate, contacted the authors of the published articles for clarification on such data. Articles identified through other sources (e.g., known to authors), as well as those cited in the retained articles, were also considered for inclusion.

2.3. *Assessment of methodological quality*

As done previously by Sarmento et al.,[17] the retained articles were each scored on a binary scale (0/1) used to assess quality in line with 16 individual quality criteria. These criteria were based on whether articles included: (1) a clear study purpose, (2) a review of relevant literature, (3) an appropriate study design for the research question, (4) a detailed description of the sample, (5) a justification of the sample size, (6) informed consent, (7) and (8) reliable and valid outcome measures, (9) a detailed description of methods, (10) statistically significant findings, (11) an appropriate method of analysis, (12) a justification for importance to practice, (13) a description of drop-outs (if any), (14) appropriate conclusions given the study design, (15) implications for a given practice, and (16) the limitations of the research.

An option was provided for items 6 ("Was informed consent required?") and 13 ("Were any drop-outs reported?"). If these criteria were "not applicable" to the article, then these 2 criteria were excluded as an option. For example, it must be considered that observational studies are not always required to obtain consent and will not necessarily have drop-outs to report. Therefore, this situation eliminates the negative impact that a zero score may have on the article quality because it may not be applicable to the article. A percentage was calculated for each article as the summation of the quality score, divided by the relevant criteria included for that research design, thereby allowing comparisons among articles of different designs. Studies were characterized as having either low (≤50%), good (51%−75%), or excellent (>75%) methodological quality.

3. Results

3.1. Study identification and selection

The initial database search returned 72 articles, and 1 article was located by the researchers during manual searches. These 73 articles were then exported to reference-managing software (Endnote X9; Clarivate Analytics, Philadelphia, PA, USA) and duplicates were subsequently removed ($n = 4$). The titles and abstracts of each entry (69 articles) were then screened for their relevance, which resulted in the rejection of 50 articles from the analysis. Following this trimming, the full texts of the remaining 19 articles were read diligently. Of the 19 articles, 8 were excluded due to their irrelevance to the topic area. Following the full screening process, 11 articles were accepted for the systematic review (Fig. 1).

3.2. Methodological quality

Quality scores are reported in Table 1; 10 studies were categorized as having excellent methodologic quality, with 1 reported as good. A mean quality score of 87.5% was established for the 11 articles. Although none of the articles attained a rating of 100%, the vast majority (10 of 11) achieved a considerably high score (>85%). None of the studies met Criterion 13, although 4 studies were observational, so this criterion was not applicable. Minimal information pertaining to the justification of the sample size was given for 6 studies, and of the 11 articles analyzed, 3 failed to address Criterion 16.

3.3. Study characteristics

A total of 296 individuals participated in the studies reviewed. The studies reported data on the following populations: professional ($n = 160$, 54.1%), professional academy ($n = 16$, 5.4%), semi-professional ($n = 10$, 3.4%), university-

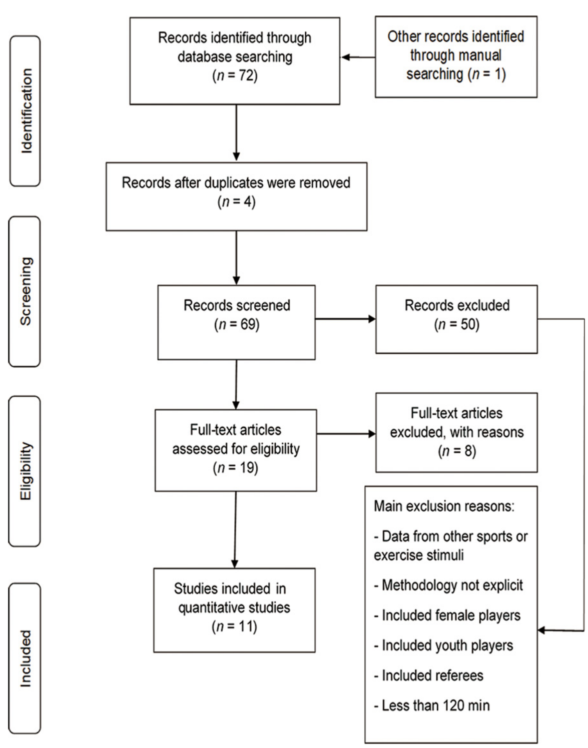

Fig. 1. The PRISMA flow diagram highlighting the study selection process for the present systematic review. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-analyses.

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Table 1
Quality assessment of the articles for the review according to Sarmento et al.[15]

Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score	%
Russell et al. (2015)[18]	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	14/16	87.5
Peñas et al. (2015)[20]	1	1	1	1	0	n/a	1	1	1	1	1	1	n/a	1	0	1	12/14	85.7
Winder et al. (2018)[19]	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	14/16	87.5
Harper et al. (2016)[16]	1	1	1	1	1	1	1	1	1	0	1	1	n/a	1	1	1	14/15	93.3
Harper et al. (2016)[23]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	15/16	93.8
Stevenson et al. (2017)[22]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	15/16	93.8
Kubayi and Toriola (2018)[21]	1	0	1	1	0	n/a	1	1	1	1	1	0	n/a	1	1	0	10/14	71.4
Harper et al. (2016)[24]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	14/16	87.5
Harper et al. (2016)[25]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	14/16	87.5
Goodall et al. (2017)[27]	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	14/16	87.5
Harper et al. (2014)[26]	1	1	1	1	0	1	1	1	1	1	1	1	n/a	1	1	1	14/15	93.3

Notes: Low methodology quality (<50%), good methodology quality (51%−75%), and excellent methodologic quality (>75%). n/a = not applicable

standard (n = 64, 21.6%), and practitioners (n = 46, 15.5%). The participants' ages (20 ± 3 years, mean ± SD) were identified for the experimental research studies (n = 8), but age was not disclosed for the observational studies (n = 3). The majority of studies were quantitative (n = 10), with 1 study categorized as mixed methods (i.e., both quantitative and qualitative). A total of 5 of the investigations were conducted on match-play (45.5%), 5 studies used soccer-specific simulations (45.5%) and the findings in 1 article were based on practitioner perceptions of ET (9.0%). The 11 articles analyzed in this systematic review were published since 2014.

3.4. Organization of data

The studies incorporated within this review included relevant information pertaining to either (1) observations of professional matches that included ET, (2) a 120-min simulation (formatted as per a soccer match), or (3) the current practices of soccer practitioners with reference to ET. In order to classify the major topics of research associated with ET, one researcher categorized the papers, with debates resolved by discussion until a consensus of the entire research team was reached. Records were subsequently categorized into 5 main themes, with some articles containing data related to ≥2 themes. These themes were as follows: (a) movement demands of ET (3 articles), (b) performance responses to ET (8 articles), (c) physiological and neuromuscular responses during ET (5 articles), (d) nutritional interventions (3 articles), and (e) recovery and ET (3 articles).

3.5. Movement demands of ET

As outlined in Table 2, 3 studies analyzed the movements demands of ET through the use of global positioning systems (GPS) and micromechanical-electrical systems.[18−20] Premier League players were observed through the use of 10-Hz tracking devices. The players covered a distance of 14,106 ± 859 m over 120 min, with an additional 3213 ± 286 m covered during ET. In the same match, players performed 50 ± 18 sprints and covered 883 ± 400 m of high-speed (HS) distance across 120 min, with 12 ± 6 of those sprints and 153 ± 105 m of the HS distance being completed during the ET period. Furthermore, the study reported 946 ± 40 accelerations (>0.5 m/s^2) across 120 min, with 221 ± 14 accelerations during ET. A total of 908 ± 36 decelerations were observed over the course of the 120 min, with 207 ± 16 decelerations being completed during ET.[18] Winder et al.[19] identified similar data (i.e., 15,400 ± 900 m of distance covered across 120 min of match-play) by 4 professional players competing in the third tier of English soccer. In addition, lower HS distance (791 ± 99 m) was observed across 120 min of match-play in Winder et al.'s study.[19] These players also completed many fewer accelerations (358 ± 52) and decelerations (169 ± 38) over the course of 120 min. Peñas et al.[20] analyzed the physical performance data of 99 outfield players from seven matches that required ET during the FIFA World Cup held in Brazil in 2014. During the tournament, players covered an average total distance of 12,245 m across 120 min of match-play, with 2962 m covered during ET. Furthermore, Peñas et al.'s[20] study reported 42 sprints during a 120-min match, with 9 sprints being completed during ET.

3.6. Performance responses to ET

In the 8 studies involving performance responses to ET, 5 analyzed physical and technical performance variables during match-play[18,20,21,26] whilst the remaining 4 assessed performance using free-running soccer simulations[22−25] (Table 3). A 12% reduction in total distance covered during ET (107 m/min) compared to 90-min (121 m/min) of match-play was observed in reserve team Premier League players.[18] The same study examined a HS distance of 8 m/min in 90 min and 5 m/min during ET, indicating a 37.5% relative decrease in HS running activity. However, ∼24% of the total number of sprints completed throughout the full 120 min duration (match-play + ET) were performed during ET. When comparing ET to the 90-min match duration, these players performed ∼14% fewer accelerations and 12.5% fewer decelerations; both actions were defined as number of actions completed at >0.5 m/s^2.[18] Similarly, movement data from 56 professional players during the 2016 UEFA European Championship[21] revealed that a total distance of 113 ± 10 m/min was covered during the first half, 107 ± 9 m/min was covered during the second half, and 98 ± 10 m/min was covered during ET. Thus, 13% less relative distance was covered during ET than was covered in the first half.

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Table 2
Studies investigating movement demands of soccer during the ET period.

References	Matches/ players	Data collection method	Variables measured	Key results
Russell et al. (2015)[18]	One reserve ET match/ English Premier League outfield players ($n = 5$).	10 Hz GPS units. Data collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	TD (m). Distance covered (m/min). High speed distance covered (m). Total number of sprints. Total number of Acc (>0.5 m/s/s) and Dec (>0.5 m/s/s).	TD: 14,106 ± 859 m across 120 min; 3213 ± 286 m during ET. High speed distance: 883 ± 400 m across 120 min; 153 ± 105 m during ET. Number of sprints: 50 ± 18 across 120 min; 12 ± 6 during ET. Number of Acc: 946 ± 40 across 120 min; 221 ± 14 during ET. Number of Dec: 908 ± 36 across 120 min; 207 ± 16 during ET.
Peñas et al. (2015)[20]	Seven ET matches from 2014 FIFA World Cup/International outfield players ($n = 99$).	Official FIFA World Cup website: https://www.fifa.com/worldcup/archive/brazil2014/statistics/players/distance.html. Data collected across first half, second half, and ET).	TD (m/min). Distances covered at low, medium and high speeds (km/h). Top speed (km/h) and avg number of sprints (reps/min).	TD: 12,245 m across 120 min; 2962 m during ET. Top sprint speeds: 24.06 ± 3.31 km/h during ET. Avg number of sprints/min: 0.31 ± 0.14 reps/min during ET.
Winder et al. (2018)[19]	Three matches (2 league and one cup)—only one ET match/English Championship outfield players ($n = 4$).	10 Hz GPS units. Data collected from MD1, MD2 (120 min), and MD3.	TD (m). High speed distance covered (>18 km/h; m). Number of Acc (> 2m/s/s) and Dec (>2 m/s/s).	TD: 15,400 ± 900 m across 120 min. High speed distance: 791 ± 99 m across 120 min. Number of Acc: 358 ± 52 across 120 min. Number of Dec: 169 ± 38 across 120 min.

Note: data are reported as mean ± SD.
Abbreviations: Acc = acceleration; avg = average; Dec = deceleration; ET = extra-time; GPS = global positioning system; I1 = 00:00−14:59 min; I2 = 15:00−29:59 min; I3 = 30:00−44:59 min; I4 = 45:00−59:59 min; I5 = 60:00−74:59 min; I6 = 75:00−89:59 min; I7 = 90:00−104:59 min; I8 = 105:00−119:59 min; MD1 = match day 1; MD2 = match day 2; MD3 = match day 3; reps = repetitions; TD = total distance.

Reductions in 30-m sprint velocity (∼3%) and sprint maintenance (∼4%) have been observed following 120-min *vs.* post 90-min measures of simulated-soccer exercise in Premier League academy players.[25] Similarly, a decrease in 20-m sprint velocity following ET has been observed when compared to pre-first-half (∼7%), post-first-half (∼5%), pre-second-half (∼2%), and post-second-half (∼2%) in university-standard players.[22] Another study observed reductions in 15-m sprint velocity during ET compared to measures taken during the first and second halves of simulated match-play in a different cohort of professional academy players.[24] Regarding technical performance, Harper et al.[26] found that the total number of successful dribbles was reduced and that the number of successful and total passes decreased by ∼20% during the last 15 min of ET compared to corresponding measures of technical performance during the first half. Furthermore, with the use of soccer-specific protocols for university-standard soccer players, reductions in both dribbling[23] and shooting[22] performance have been observed during ET.

3.7. Physiological and neuromuscular responses during ET

A total of 5 studies[22–25,27] investigated the physiological and neuromuscular responses during ET using diverse equipment and methods (Table 4). Stevenson et al.[22] observed increases in plasma glycerol, nonesterified fatty acids, interleukin-6 and epinephrine (adrenaline), as well as reductions in blood glucose and lactate concentrations during ET compared to 90 min of simulated match-play. Findings in studies of professional academy soccer players suggest that ET has an influence on markers of bicarbonate, base excess, hemoglobin and blood pH. Similarly, significant reductions have been analyzed in blood pH (0.01−0.03) levels during the final 15 min of ET *vs.* baseline, half time, and the first 15 min of ET.[24] Furthermore, Goodall et al.[27] observed that ET provoked an additional development of neuromuscular fatigue involving mainly the central nervous system, with significant perturbations in voluntary activation of the knee extensors and maximum voluntary quadriceps force produced at 120 min *vs.* pre-match, HT, and 90 min.

3.8. Nutritional interventions

A total of 2 articles[22,25] investigated the efficacy of nutritional intervention during the ET period, and 1 empirical observation[16] assessed the nutritional practices of soccer players in relation to ET through practitioner feedback. Harper et al.[25] observed that carbohydrate (CHO) gels had no impact on physical performance; however, a 16% ± 17% increase in blood glucose and a 29% ± 20% improvement in dribbling precision during the final 15 min of ET was delineated. Stevenson et al.[22] found that consumption of a low glycemic index (GI) drink better maintained blood glucose concentrations by 13% compared to high GI in the second half of simulated

Table 3
Studies investigating performance responses to the ET period of soccer.

Reference	Matches/Protocol/ Players	Data collection method	Variables measures	Key results
Harper et al. (2014)[26]	Eighteen matches. European soccer teams (specified as ranging from first to 3rd tier of their domestic leagues) and International teams. Number of outfield players per match ($n = 15 \pm 1$).	Footage was obtained from televised recordings and soccer clubs. Data collected were manually coded by an experienced performance analyst. Data collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	Successful passes, unsuccessful passes, total passes, pass accuracy (%), successful dribbles, unsuccessful dribbles, total dribbles, dribble accuracy (%), shots on target, shots off target, total shots, shot accuracy (%), successful crosses, unsuccessful crosses, total crosses, cross accuracy (%), and ball time in play (s).	Successful passes: ↓ I8 *vs.* I1, I2, I3, I4, I7. Total passes: ↓ I8 *vs.* I1, I3, I4, I7. Successful dribbles: ↓ I8 *vs.* I1, I3. Ball in play: ↓ I8 *vs.* I1. All other technical performance variables: ↔ were observed.
Peñas et al. (2015)[20]	Seven ET matches from the 2014 FIFA World Cup/International outfield players ($n = 99$).	Official FIFA 2014 World Cup website: https://www.fifa.com/worldcup/archive/brazil2014/statistics/players/distance.html. Data collected across three different match periods (first half, second half, and ET).	TD (m/min). Distances covered at low, medium, and high-speeds (km/h). Time spent in low- (≤11.0 km/h), medium- (11.1−14.0 km/h), and high speed (≥14.1 km/h) activities (%). Top sprint speed (km/h) and number of sprints (reps/min).	TD: ↓ during ET and second half *vs.* first half. Top sprint speeds: ↓ during ET vs. second half and first half. Avg number of sprints per min: ↑ during first half *vs.* second half and ET.
Russell et al. (2015)[18]	One reserve team ET match/ English Premier League outfield players ($n = 5$).	10 Hz GPS units. Data collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	TD (m). Distance covered (m/min). High speed distance covered (m). Total number of sprints, total number of Acc and total number of Dec (>0.5 m/s/s).	TD: 121 m/min across 90 min and 107 m/min during ET (12% ↓). high speed distance: 8 m/min durng 90 min and 5 mmin across ET (37.5% ↓). Acc: 6m/min throughout 90 min and 7 m/min during ET (~14% ↓). Dec: 8 m/min during 90 min and 7 m/min throughout ET (12.5% ↓).
Harper et al. (2016)[23]	120-min of simulated soccer match-play. University-standard outfield soccer players ($n = 10$).	No information available on data collection methods. Data collected across 4 time points: Post first half, pre second half, FT, and post-ET.	CMJ height (cm), 20-m sprint (s) and 15-m sprint (m/s).	During final 15 min of ET: 15-m sprint speeds ↓ *vs.* all other time points. Following ET: 20-m sprint speeds ↓ *vs.* baseline and post first half. CMJ height ↓ *vs.* with baseline.
Harper et al. (2016)[24]	120 min of simulated soccer match-play/English Premier League academy soccer outfield players ($n = 8$).	15-m sprint velocities measured during first half, second half, and ET.	15-m sprint velocities (m/s).	Sprint velocities: ↓ by 6% during ET *vs.* first half.
Harper et al. (2016)[25]	120 min of a modified version of the soccer match simulation. English Premier League academy soccer outfield players ($n = 8$).	Video footage. (Data collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	30-m sprint velocities (m/s), 30-m repeated sprint maintenance (%), CMJ height (cm).	30-m sprint velocities: ↓. 30-m repeated sprint maintenance: ↓. CMJ height: ↓. (Comparisons are post-ET measures *vs.* post-90-min measures).
Stevenson et al. (2017)[22]	120-min soccer match simulation. University-standard soccer players ($n = 22$).	Electronic Opto Jump system, timing gates and methods similar to that of Russel, Benton, and Kingsley[51] were used to assess skill performance. Assessments were completed pre first half, post first half, pre second half, post second half, and, post-ET.	Peak 20-m sprint velocities (m/s), sprint decrement index (%), jump height (cm), shot speed (m/s), shot precision (cm), mean 15-m sprint velocities, (m/s), dribbling speed (m/s), dribbling precision (cm), and dribbling success (%).	Jump height: ↓ following ET *vs.* pre first half and post second half. Sprint performance: Relatively ↓ during ET *vs.* 75- to 90-min of simulated match-play. Shot speed: ↓ following ET *vs.* pre-values (4.3%) and post second half (2.9%). Dribbling speed: ↓ during ET

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Table 3 (Continued)

Reference	Matches/Protocol/ Players	Data collection method	Variables measures	Key results
				vs. 0 to 15-min of simulated match-play. Shooting performance: ↔ during ET.
Kubayi and Toriola (2018)[21]	Four matches from the 2016 European Championship, six teams/European players ($n = 59$).	InStat camera tracking system. Data collected across 120 min and categorized into first half, second half, and, ET.	TD (m/min), walking (m/min) jogging (m/min), running (m/min), high-speed running (m/min), and sprinting (m/min). Walking (0−7 km/h), jogging (7.1−14.5 km/h), running (14.6−20 km/h), high-speed running (20.1−25 km/h), and sprinting (>25 km/h).	TD: ↓ during first half *vs.* ET by 13%. TD covered by wide midfield players: ↓ by 17% during first half *vs.* ET. Sprinting performance ↓ during ET *vs.* first half. Greater ↓ were observed in attacking players *vs.* all other positions.

Notes: data are reported as mean ± SD; ↓ = decreased/lower than; ↑ = increased/higher than; ↔ = no difference.
Abbreviations: CMJ = countermovement jump; ET = extra-time; FT = full time; FWC = Fédération Internationale de Football Association World Cup; GPS = global positioning systems; I1 = 00:00−14:59 min; I2 = 15:00−29:59 min; I3 = 30:00−44:59 min; I4 = 45:00−59:59 min; I5 = 60:00−74:59 min; I6 = 75:00−89:59 min; I7 = 90:00−104:59 min; I8 = 105:00−119:59 min; RSA = repeated sprint ability; TD = total distance.

match-play, particularly between the 75- and 90-min marks, but the drinks had no effect during ET. Soccer practitioners specified that hydration and energy provision (e.g., high CHO gels and drinks, high GI foods, caffeine, and protein) were prioritized in the intervals prior to and during ET.

3.9. Recovery and ET

A total of 3 articles sought to determine the recovery response following matches that required ET.[16,18,19] Creatine kinase concentrations increased at 24 h (236% ± 92%) and 48 h (107% ± 89%) following ET compared to baseline in Premier League players. Observations of countermovement jump height found reductions of 17.8% ± 11.2% at 24 h and 7.4% ± 3.2% at 48 h following ET in the same pool of players.[18] Moreover, a case report found that ET impeded both subjective (wellness) and objective (countermovement jump height) measures of recovery 36 h post-match compared to 36 h following a 90-min match in the same weekly micro-cycle.[19] Additionally, the findings from a mixed-method survey suggested that practitioners working in professional soccer believe that more research should be conducted on ET, particularly on fatigue responses (including recovery) and acute injury risk.[16]

4. Discussion

The purpose of this systematic review was to collate, summarize, and evaluate the current ET literature in order to determine the current practices being employed within soccer, highlight common research trends and identify future research opportunities. Accordingly, the studies were grouped for the purpose of assessing the individual facets associated with ET. The main findings from this review are as follows: (a) performance (i.e., physical and technical/skill) is reduced, relative to match duration (i.e., meters per minute), during ET compared to a 90-min match, (b) consumption of CHO gels may attenuate reductions in dribbling performance, and (c) matches that require ET may delay recovery further when compared to 90-min matches.

4.1. Movement demands of ET

The International Football Association Board has approved the use of GPS technologies during competitive matches, thus allowing a method of assessing the within-match movement response of players. This strategy is now commonplace in professional soccer and permits the measuring of variables such as distance covered, HS running distances, number of sprints, and number of accelerations and decelerations.[28,29,30] Russell et al.[18] were the first researchers to investigate the movement demands of soccer players during ET. This seminal work influenced further investigations in which professional players were observed during a fixture-congested micro-cycle (i.e., 3 matches in 7 days) that incorporated an ET match.[19] The disparities in HS distance are unsurprising in that the players analyzed competed 2 tiers apart, and evidence suggests that HS performance is superior in high-level players during match-play.[6] Furthermore, the match requiring ET within the fixture-congested micro-cycle[19] was played against higher caliber league opposition (differing by 47 league places at the time of the match), and contextual factors such as self-pacing strategies and match location may have influenced the performance of players.[31] Furthermore, the 4 players used played 4 discrete positions (2 center backs, 1 fullback, and 1 central midfielder), and when expressed relative to playing time, there were considerable differences between individuals for the aforementioned performance metrics. The data were not separated into periods of match-play (i.e., first half, second half, and ET) and therefore we were unable to ascertain whether performance was affected during ET. Moreover, small sample sizes were used within both studies, making findings difficult to extrapolate, especially when differentiating findings across playing positions.

In contrast, Peñas et al.[20] investigated the movement demands of a substantial number of players ($n = 99$), thus addressing the limitation of using small samples used in both

Table 4
Studies investigating physiologic and neuromuscular responses during the ET period of soccer.

Reference	Matches/protocol/players	Data collection method	Variables measured	Key results
Harper et al. (2016)[25]	120 min of a modified version of the soccer match simulation. English Premier League academy soccer outfield players (*n* = 8).	Fingertip capillary blood samples. HR monitor. Data collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	Blood glucose, lactate, and sodium (mmol/L).	Blood glucose concentrations: ↑ in CHO (5.6 ± 0.9) *vs.* PLA (4.6 ± 0.2) trials during E7. Blood lactate and sodium concentrations: ↔ were observed during ET *vs.* other time points.
Harper et al. (2016)[23]	120-min of simulated soccer match-play. University-standard outfield soccer players (*n* = 10).	Fingertip capillary and venous blood samples collected across time points (I1, I2, I3, I4, I5, I6, I7, and I8).	CK (U/L), insulin (pmol/L), NEFA (mmol/L), glycerol (mmol/L), IL-6 (pg/mL), and HR mean (b/min).	CK: ↑; NEFA: ↑; glycerol: ↑; insulin: ↔; IL-6: ↔ during ET *vs.* pre-exercise, post first half and pre second half. HR mean: ↔ were observed during ET *vs.* other time-points.
Goodall et al. (2017)[27]	120-min of simulated soccer match-play. University-standard and semi-professional outfield soccer players (*n* = 10).	EMG activity was measured by Surface Ag/AgCl electrodes. HR data measured using HR monitors. Data collected pre-match, HT, FT, and following ET.	ERT (N), MVC (%), $Q_{tw,pot}$ (%), VA (%), VA_{TMS} (%), RF M_{max} amplitude (mV), RF rms EMG/M, RF MEP/M_{max} area (%), VL M_{max} amplitude (mV), VL rms EMG/M, VL MEP/M $_{max}$ area (%), MRFD (N/s), CT (ms), MRR (N/s), $RT_{0.5}$ (ms), and HR (b/min).	MVC: ↓ throughout match-play, with ↑ decrements found in ET *vs.* HT and FT; $Q_{tw,pot}$ amplitude: ↔ were observed from HT to ET. VA: ↓ following ET *vs.* baseline; VA_{TMS}: ↓ during ET *vs.* baseline, although ↔ between ET, FT, and HT; RF rms EMG/M: ↓ following ET *vs.* baseline.
Harper et al. (2016)[24]	120-min of simulated soccer match-play. Professional academy soccer players (*n* = 8).	Capillary blood samples (170 μL) were taken at baseline, pre-exercise, HT, and at 15, 30, 45, 60, 75, 90, 105, and 120 min.	Blood calcium (mmol/L), potassium, (mmol/L), pH (AU), base excess (mmol/L), lactate (mmol/L), bicarbonate (mmol/L), and hemoglobin (mg/dL) concentrations.	Base excess: ↓ at 120 min *vs.* HT (−110% ± 159%), second half and 105 min (−219% ± 280%). Bicarbonate: ↓ at 120 min *vs.* 105 min (23.7% ± 3.3%) and ↑ at 105 min *vs.* HT (22.2% ± 1.4%). Hemoglobin: ↑ at 120 min *vs.* baseline (6.8% ±5.6%) and pre-exercise (7.9% ± 9%).
Stevenson et al. (2017)[22]	120-min soccer match simulation. University- standard soccer players (*n* = 22).	Venous blood samples were collected at rest, pre-match, 15 min, 30 min, 45 min, HT, 60 min, 75 min, 90 min, 105 min, and 120 min.	Lactate (mmol/L), glycerol (mmol/L), NEFA (mmol/L), IL-6 (pg/mL), epinephrine (pmol/L), HR peak (b/min), and HR mean (b/min).	Blood lactate: ↓; glycerol: ↑; NEFA: ↑; IL-6: ↑; epinephrine: ↑; HR peak: ↑; HR mean: ↑ were observed during ET *vs.* 90-min in the PLA group.

Notes: data are reported as mean ± SD; ↓ = decreased/lower than; ↑ = increased/higher than; ↔ = no difference.
Abbreviations: CHO = carbohydrate; CK = creatine kinase; CT = contraction time; EMG = electromyography; ERT = estimated resting twitch; ET = extra-time; FT = full time; HR = heart rate; HT = half time; I1 = 00:00−14:59 min; I2 = 15:00−29:59 min; I3 = 30:00−44:59 min; I4 = 45:00−59:59 min; I5 = 60:00−74:59 min; I6 = 75:00−89:59 min; I7 = 90:00−104:59 min; I8 = 105:00−119:59 min; IL-6 = interleukin-6; MEP = motor evoked potential; M^{max} = maximal M-wave; MRFD = maximum rate of force development; MRR = maximum rate of relaxation; MVC = maximal voluntary contraction; NEFA = nonesterified fatty acids; PLA = placebo; $Q_{tw,pot}$ = potentiated knee-extensor twitch force; RF = rectus femoris; rms = root-mean-squared; RT0.5 = half relaxation time; VA = voluntary activation measured using motor nerve stimulation; VA_{TMS} = voluntary activation measured using motor cortex stimulation; VL = vastus lateralis.

the aforementioned studies. The data from 7 matches analyzed by Peñas et al.[20] at the 2014 FIFA World Cup showed that positional differences existed (i.e., central midfielders cover more total and HS distance than other positions) for both 90-min matches and ET. However, irrespective of playing position, a decrease in movement during ET is evident, although it has yet to be elucidated whether this is attributable to physical fatigue or to a tactical approach. Therefore, investigating performance through simulated match-play may provide novel information on the mechanisms behind the reduced movement capacity.

4.2. Performance responses to ET

The match-to-match and between-player movement metrics are inherently variable within soccer. The literature suggests that match coefficients of variation are between 26% (total distance) and 30% (HS running distance),[32−34] and player intraclass correlations are as sizeable as 32% and 39% for total and HS distance, respectively.[35] Thus, match data must be interpreted with caution; hence, the use of laboratory-controlled investigations. Specifically, free-running soccer match simulations are preferable should researchers wish to incorporate skill actions, though these protocols are limited when attempting to replicate the mechanistic demands associated with match-play.[23] Treadmill-based protocols elicit a mechanistically valid fatigue response comparable to match-play, while they also eliminate the pacing element, because fixed bouts of workload can be performed.[36] This allows fatigue-induced inferences to be drawn from a change in response as opposed to a subconscious attempt to self-pace or to tactical alterations often observed during match-play.[37] However, simulated match protocols are lacking in ecological validity and are unable to replicate a fatigue response comparable with match-play, especially while replicating the demands on a treadmill, because players are unlikely to attain maximum speeds.[23] The use of soccer-specific protocols also allows the comparison of individual changes to baseline scores. Therefore, when translating sprint performance during match-play, it is important to consider the individual speed of players, since slower players may not reach the thresholds at their given maximal sprinting speed. Reduced sprint speeds observed during soccer protocols could perhaps be linked to the reduced physical capacity (i.e., HS running) because players are not able to reach and sustain these intensities. However, the extent to which the findings of simulated match-play translate to a soccer match remain equivocal.

The first study to quantify changes in technical performance throughout 120 min of soccer was an empirical observation of 18 professional matches.[26] The researchers observed a reduction in the total number of passes and successful dribbles, although they speculate that this may not be indicative of a reduction in technical proficiency per se. It is more likely that players lacked the physical capacity to be involved with build-up play and thus complete these technical actions, and therefore is potentially related to the reduced physical capacity observed previously.[18,19] However, it is not clear whether this can be ascribed to increased fatigue or to player perceptions and subsequent pacing strategies. For example, anecdotal observations suggest that players may consciously reduce their work rate during ET and adopt a defensive approach in anticipation of a penalty shootout.[9] This may also explain the reason that matches are not often decided during ET. However, technical information about ET is scarce, and the precise mechanisms (i.e., physical and/or mental fatigue) modulating skill proficiency need investigating further. Given the likelihood that the performance decrements are associated with temporal and cumulative fatigue, understanding the physiological mechanisms that influence performance during ET may have important implications during tournament and cup scenarios.

4.3. *Physiological and neuromuscular responses during ET*

Goodall et al.[27] observed that 120 min of simulated soccer elicited an additional development of central nervous system fatigue through reductions in the maximal voluntary quadriceps force. It has previously been suggested that increases in peripheral biomarkers influence type III and IV nerve afferents, thus initiating temporary and cumulative reductions in central motor output.[38–40] Reductions in central motor output could perhaps result in a player being at an increased risk of injury due to impaired muscular and cognitive functions (e.g., reactions, decision making, and perceptions).[41,42] The observed increases in central fatigue during ET could theoretically explain the decrements in physical performance and increased likelihood of injury, particularly during match-congested schedules.

It is unlikely that such trivial changes in pH (i.e., <0.2) observed by Harper et al.[24] can be associated with acidosis or result in the deleterious performance of 15-m sprints. This notion is supported by the lack of relationship observed between changes in sprint performance and blood pH in the same cohort. Investigations are required to determine whether the additional pressures of actual match-play (i.e., opposition players and environmental pressures) are likely to further exacerbate performance in comparison to simulated soccer matches.

Throughout a 90-min period of match-play, soccer players reach 70% of their maximal oxygen uptake[43] and mean and peak heart rate values of 82% and 97%, respectively.[34,44] To fuel this exercise, glycogen is required during match-play, although evidence suggests that availability of intramuscular glycogen markedly decreases when exercise duration exceeds 90 min, after which fat stores are predominantly utilized.[45] The data on ET suggest a temporal change occurs in the primary energy pathway utilized as a match progresses through 90 min and into ET (i.e., the pathway switches to predominately fat oxidation).[22] This could be due to elevated epinephrine and diminished insulin concentrations. Increased levels of epinephrine stimulate muscle glycogenolysis through activation of phosphorylase α,[46] and dampened insulin concentrations promote lipolysis because it inhibits the activation of protein kinase A and Akt.[47] Because fatty acid metabolism is not the optimal energy pathway required for HS exercise, this could plausibly explain the transient impairments in physical performance observed during ET. However, before interpreting these data, it is prudent to highlight the fact that substrate use has merely been estimated during ET. Therefore, direct measurements taken during simulated match-play is a potential avenue for future research.

Because epinephrine concentrations increase markedly during ET,[22] it could be hypothesized that muscle glycogen decreases further during this additional 30-min period. However, to date, no study has measured muscle glycogen in response to 120 min of soccer match-play (simulated or otherwise). Krustrup et al.[48] took muscle biopsies from players during a 90-min soccer match and observed significant reductions in glycogen concentrations at 90 min compared to pre-match. Because these concentrations were at critically low levels for some players, any further decrease could negatively impact performance and recovery. During 120 min of cycling, Logan-Sprenger et al.[49] observed significant reductions in muscle glycogen from 80 min to 120 min. These reductions were concomitant with increases in fat oxidation, circulating nonesterified fatty acids and epinephrine concentrations. Although they were from a cycling exercise stimulus, these data support the findings of Stevenson et al.[22] Additional work is needed to verify whether reductions in muscle glycogen are uniform with both the blood glucose and cycling data above, and whether nutritional intervention, such as CHO intake, can attenuate reductions when matches proceed to ET.

4.4. *Nutritional interventions*

Acute CHO provision is currently used in soccer in an attempt to mitigate performance decrements. The improved skill performance following CHO consumption has been associated with an increased supply of cerebral glucose (increasing

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oxidative metabolism) and protection against central nervous system fatigue.[50,51] Although somewhat extraneous and not specific to soccer, empirical evidence suggests that the provision of CHO over 120 min of cycling exercise can ameliorate reductions in performance.[52] Currently, there is a dearth of scientific literature that has investigated nutritional interventions for soccer players during ET despite the fact that, in an online questionnaire, soccer practitioners ranked nutritional interventions as the most important area for future research in relation to ET.[16] Furthermore, practitioners recommend that CHO and protein intake be increased immediately following ET and maintained up to 48 h following an ET match in the belief that it accelerates recovery.[16] Additional study related to this issue is needed.

4.5. Recovery following ET

The impact of 120 min of soccer match-play on the recovery process has received little attention in the literature. Practitioner surveys showed that 50% of those completing the survey do not alter preparatory strategies prior to a match that might require ET, although 89% do adjust recovery modalities.[16] This is perhaps not surprising considering that the small body of literature suggests that reductions in HS distance, and dribble and passing accuracy are evident during a 90-min match that was played 64 h after an ET match in the same weekly micro-cycle.[19] Therefore, more robust investigations are needed with larger sample sizes, controlled soccer-specific protocols and various recovery measures. Increased understanding of changes in recovery following ET and the efficacy of commonly used recovery methods could better inform soccer practitioners of which practices might be optimal following ET.

4.6. Methodologic limitations

We acknowledge that confounding factors, methodologic inconsistencies within the literature (e.g., competitive level of players and HS thresholds), and measurement errors (e.g., GPS devices and HR monitors) may have affected our analysis of these studies. A lack of experimental rigor in the limited number of ET studies available may have also influenced our analysis. Nonetheless, our quality appraisal classified 10 of the 11 studies as excellent. Another potential flaw is the exclusion of female players in the studies we analyzed. However, comparisons between the sexes are difficult given the physiologic differences,[53] as well as the fact that the only published ET research that includes females involves a shorter duration of match-play (i.e., two 10-min periods).[54] Finally, the inclusion of studies published only in the English language may have eliminated other potentially relevant studies published in other languages.

5. Conclusions and directions for future research

Very little research has been conducted on soccer matches that require the additional period of ET. Investigations using 120-min soccer simulations and actual match-play have observed decreases in physical, technical and physiological parameters, as well as compromised recovery. The lower intensities of play identified during ET could partly be due to the change in the predominant substrate pathway (aerobic glycolysis to fat oxidation) used for energy production. However, further investigations are necessary since mechanical fatigue may cause these reductions in intensity, altering the predominant fuel source. Thus, the need to use bouts of standardized workloads under controlled conditions to profile the fatigue and recovery responses of soccer players is justified. These studies should be undertaken with the intention of reducing fatigue-related injuries across successive matches during fixture-congested periods that involve ET scenarios.

Competitive match-play may yield ecologically valid performance responses; however, it is likely that individual profiles during a soccer match may vary, given the influence of situational variables and between-match and inter-individual variations. This premise also applies to the disparate activity profiles of each playing position. Although there is a plethora of literature documenting the demands of match-play across various playing positions over 90 min,[55–57] there is currently a lack of position-specific information during ET periods. Furthermore, the majority of soccer simulations are based on an average profile and fail to account for positional differences. Therefore, through the longitudinal monitoring of players, researchers should endeavor to quantify external load characteristics according to playing positions during tournaments and cup competitions. By doing so, it may be possible to collate an adequate grouping of data that provides a comprehensive assessment of the influence of ET on the discrete demands of each playing position. Soccer investigations have typically focused on 90 min of match-play, but this research may lack applicability to ET in many different areas of the sport. For example, there is a notable absence of research on female soccer players and their performance during ET. Likewise, research on cognitive performance during ET is an area in which additional research is needed. There is also a need for additional investigations into the extent to which ET has an effect on the physical and technical performance parameters and recovery both for male and female soccer players. Because competitive tournaments are often held in hot climates, the impact of playing ET in high ambient temperatures (e.g., $>30^{\circ}C$) should be investigated since a player's performance, recovery and overall health may be negatively affected by playing ET in hot weather. Similarly, research on the effect of playing ET at high altitudes is needed, particularly since the FIFA World Cup in 2026 may be played in stadiums located in cities at elevations $\geq$1500 m (e.g., Mexico City's Estadio Azteca at 2915 m, Guadalajara's Estadio Akron at 1566 m, and Denver's Mile High Stadium at 1610 m).

It should be noted that ET occurs relatively infrequently compared to typical 90-min matches, although it is recommended that coaches and practitioners prepare for this possibility in tournament scenarios. Individual players experiencing temporary fatigue during 120-min matches should be replaced, especially with FIFA authorizing the introduction of a fourth substitution during ET; in a change endorsed by applied practitioners.[16] Furthermore, we advocate carefully orchestrated fueling strategies during the days leading up to matches that may require ET, and that CHO be provided on match day

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(including 5 min prior to ET). This may require additional effort so that individual player preferences are readily available in the 5-min break prior to ET, thus increasing player compliance. Administering nutrition that has ergogenic properties and elicits faster absorption rates, such as caffeine gum, may be efficacious prior to ET.[58] Additionally, the highly taxing and intermittent nature of soccer reduces endogenous glycogen, so it is recommended that practitioners adopt nutritional strategies that replenish intramuscular and liver glycogen stores following ET matches.

Players susceptible to fatigue can be identified through the use of a number of contemporary methods, including tracking data, biochemical and hydration assessments and sleep and wellness profiles. These data may assist in making informed decisions about a player's readiness and when that player should return to training following ET matches. The time-course for a player's recovery may be delayed after an ET match compared with a typical 90-min match. However, if reductions in training load and intensities are warranted to aid recovery between matches, sport science practitioners and coaches should collaborate to ensure that players maintain optimal fitness. It may also be beneficial to adopt training programs in the period prior to competition so that players are prepared for matches that have the potential to progress to ET. Although it may be difficult to determine precisely when such training programs should be implemented during fixture-congested tournaments, it is crucial to do so in order to reduce injury risk while optimizing player performance.

Author contributions

AF and LDH wrote the first draft; RJN, MH, SL, LDC, MR, and RMP reviewed the manuscript at various stages throughout the editing process. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

All authors declare that they have no competing interests.

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