Title

The Training of Medium-Long Distance Sprint Performance in Football Code Athletes: A Systematic Review and Meta-Analysis

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Abstract

Background

Within the football codes, medium- (i.e., >20m and ≤40m) to long-distance (i.e., >40m) sprint performance and maximum velocity sprinting are important capacities for success. Despite this, no research has identified the most effective training methods for enhancing medium-long distance sprint outcomes. This systematic review with meta-analysis aimed to 1) analyse the impact of different methods to enhance medium- to long-distance sprint performance outcomes (0-30m, 0->30m and the maximum velocity phase) within football code athletes, and 2) identify how moderator variables (i.e., football code, sex, age, playing standard, phase of season) affect the training response.

Methods

A systematic search of electronic databases was conducted. A random-effects meta-analysis was performed (within-group changes and pairwise between-group differences) to establish standardised mean difference with 95% confidence intervals. This identified the magnitude and direction of the individual training effects of intervention subgroups (sport only, primary, secondary, tertiary and combined training methods) on medium-long distance sprint performance while considering moderator variables.

Results

Sixty studies met the inclusion criteria (26 with a sport only control group), totalling 111 intervention groups and 1,500 athletes. The within-group changes design reported significant improvements (small-moderate) between pre- and post-training in performance for the combined, secondary (0-30m, 0->30m) and tertiary training methods (0-30m). A significant moderate improvement was found in the max velocity phase performance for tertiary training methods only. No significant effect was found for sport only or primary training methods. The pairwise between-group differences design (experimental vs control) reported favourable performance improvements (large SMD) for the combined (0->30m), primary (Vmax phase), secondary (0-30m and Vmax phase) and tertiary methods (all outcomes) when compared with the sport only control groups. Subgroup analysis reported that the significant differences between the meta-analysis designs consistently demonstrated a larger effect in the pairwise between-group differences than the within-group change. No individual training mode was found to be the most effective. Subgroup analysis identified that football code, age and phase of season moderated the overall magnitude of training effects.

Conclusions

This review provides the first systematic review and meta-analysis of all sprint performance development methods exclusively in football code athletes. Secondary, tertiary and combined training methods appear to improve medium-long sprint performance of football code athletes. Tertiary training methods should be implemented to enhance max velocity phase performance. Both sport only and primary training methods do not appear to enhance medium-long sprint performance. Performance changes may be attributed to either or both adaptations specific to the acceleration or max velocity phases, not exclusively max velocity. Regardless of the population characteristics, sprint performance can be enhanced by increasing either or both the magnitude and the orientation of force an athlete can generate in the sprinting action.

OSF registration https://osf.io/kshqn/

Key points:

- Research evaluating of medium-long distance sprint performance in the football codes is biased towards male soccer athletes that includes tertiary training methods (e.g., strength, power and plyometrics training).
- Medium-long distance sprint performance of football code athletes can be enhanced through secondary (i.e., resisted or assisted sprinting), combined (i.e., primary or secondary and tertiary methods) (0-30m, 0->30m) and tertiary training methods (0-30m). Tertiary training methods were the only mode to significantly enhance the max velocity phase performance. However, sport only training or primary training methods did not enhance performance. Despite the use of performance outcomes >20m as a proxy measure of max velocity performance, performance changes may be attributed to either or both adaptations specific to the acceleration or max velocity phases, not exclusively max velocity.
- Independent of the population characteristics, findings suggest that practitioners should develop either or both the magnitude, and the orientation of forces, an athlete can generate and express in the sprinting action to improve medium-long distance sprint performance.

1 Introduction

Football athletes are defined as those who are competing within a football code. These typically include soccer, American Football, Canadian Football, Australian Football, rugby union, rugby league, rugby sevens, Gaelic Football and futsal. Football code athletes should be proficient at sprinting both short (i.e., 5-20m) and medium-long (>20m) distances (1-5). Although less frequent, players perform medium- (i.e., >20m and ≤40m) to long-distance sprints (e.g., >40m), enabling athletes to express maximum velocity sprinting (Vmax) capabilities, particularly from moving starts (4, 6-14). Very large associations have been demonstrated between Vmax and sprint performance (0-36.6m r=0.94 and 18.3–36.6 m, r=0.97) in football code athletes, while the relative rate of acceleration remained the same irrespective of sprinting performance, indicating that a higher Vmax enables a superior acceleration performance (8). Given that most athletes accelerate in a similar manner relative to Vmax, it may be that Vmax serves as the upper threshold or limiting factor in the acceleration phase performance. Therefore, by improving an athlete's sprinting Vmax, it may indirectly improve acceleration (8). Hence, the development of Vmax and medium-long sprint performance is a vital component of athletic performance within the football codes (15-18).

Sprint performance over distances greater than 20m (i.e., 0-30m and 0-40m split time or velocity) has been shown to be a differentiating factor between playing standards (19-21) and age categories (19, 21, 22), as well as being associated with success in key attacking and defensive performance indicators in football codes athletes (e.g., rugby sevens (16), rugby league (17, 18), soccer (23)). This body of evidence emphasises the importance of sprint performance for football performance and player development. Unlike sprinters or non-athletic populations, sprint performance development programmes in football code athletes are typically performed concurrently with multiple other potentially contrasting physical capacities (e.g., endurance) alongside the code's specific technical-tactical skills. Therefore, developing sprint performance is a challenge for all practitioners involved in the football codes (15, 19, 24). The review by Nicholson et al. (25) reported that short-sprint performance outcomes (0-5m, 0-10m and 0-20m) was enhanced concurrently with code-specific training in football code athletes, however, no research has identified the most effective training methods for enhancing medium-long distance sprint outcomes in football code athletes (e.g., 0-30m, 0-40m, 0-50m). This highlights the need for specifically targeted sprint-based research to understand the most effective, evidence-based methods for developing sprint performance over medium-long sprint distances (e.g., 30-50m).

Sprinting is a multidimensional skill with distinct phases (e.g., acceleration and Vmax). The sequential phases present shifting kinetic and kinematic outcomes as running velocity increases (26). The kinetics changes include a reduction in the relative contribution of horizontal and increasing contribution of vertical ground reaction forces (26). Kinematics outcomes include progressively greater stride length and frequency, reduced contact times and the trunk lean becomes closer to vertical (26). As a population, football code athletes exhibit different physical and technical approaches to sprinting (27, 28) when compared to well-trained sprinters. Notably, Vmax is achieved at shorter distances (e.g., 15-40m vs. 40-60m respectively) with a lower Vmax (~7-10m·s^{-1} vs. >12m·s^{-1}) compared to well-trained, male elite sprinters (8, 9, 27, 29-31). Furthermore, a higher Vmax percentage is attained at shorter distances (e.g., 90% at 13.7m in American Football (8); 96% at 21m in rugby (9)). This highlights the need for specifically targeted sprint-based research within this population.

Previous reviews of the literature and meta-analyses (32, 33) using mixed population cohorts (i.e., sprinters, team sport and non-athletic populations) and several training studies evaluating the effectiveness of sprint training interventions (e.g., (34-36)) reported that sprint performance is a trainable capacity. However, the responses to sprint development were reported to be highly variable (32, 34, 37, 38). Training effects appear to be mode-specific, with distance specific performance changes (e.g., 0-30m and 0->30m) associated with phase-specific adaptations (i.e., acceleration vs Vmax (32, 33)). Training modes are typically classified based on task specificity into the following subgroups; primary (e.g., sprint technique, sprinting), secondary (e.g., resisted or assisted sprinting) or tertiary (e.g., non-specific methods including resistance training and plyometrics) (39). Due to the limitations in the literature, it is currently unclear what method is best to enhance medium-long sprint performance both individually and across football codes. These include 1) no reviews exclusively including football code athletes, instead including sprinters and non-athletes (32, 33, 40-49); 2) no study examines all training modalities across football code athletes (32, 33, 40-49); and 3) previous systematic reviews and meta-analyses (32, 33, 41) misclassifying training modes by failing to account for the normal training practices undertaken by training intervention groups (e.g., training categorised as a resisted sled intervention also including two strength sessions per week) within their reviews and analysis. These limitations heavily influence the interpretation and knowledge associated with sprint training interventions for applying evidence-based practices within football code athletes. Hence, the effective development of medium-long sprint performance is a collective problem across codes. Conducting a cross-football codes systematic review would provide a more comprehensive overview of the available literature than an individual sport, while also comparing best methods of developing medium-long sprint performance. However**,** the magnitude and direction of the training response may be affected by "moderator" variables presenting changes based on population characteristics such as the sport (50), age (42) and sex (51) of the athlete, and training phase (e.g., pre-season (33)). Therefore, it is important to also identify the moderator variables and evaluate the extent that they may affect the resultant training effect (52).

This systematic review and meta-analysis aimed to 1) analyse the impact of different methods to enhance medium to long-distance sprint performance outcomes (0-30m, 0->30m and the max velocity phase) within football code athletes, and 2) identify how moderator variables (i.e., football code, sex, age, playing standard, phase of season) affect the training response.

2 Methods

2.1 Design and Search Strategy

A systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (53) and followed the Prospero guidelines. Due to the nature of the project, the review protocol was prospectively registered on the database for open science framework (OSF) https://osf.io/kshqn/. A systematic search of electronic databases (PubMed, The Cochrane Library, MEDLINE, SPORTDiscus and CINAHL, via EBSCOhost) was conducted to identify original research articles published from the earliest available records up to and including 04/12/2019. Boolean search phrases were used to include search terms relevant to football code athletes (population), the training intervention (dependent variable) and the sprint performance outcomes (independent variable). Relevant keywords for each search term were determined through pilot searching (screening of titles/abstracts/keywords/full texts of previously known articles). Keywords were combined within-terms using the 'OR' operator, and the final search phrase was constructed by combining the three search terms using the 'AND' operator (Table 1).

*****INSERT TABLE 1 ABOUT HERE*****

2.2 Study selection

Duplicate records were identified and removed before the remaining records were screened against the predefined inclusion-exclusion criteria (Table 2). Studies were screened independently by two researchers (BN, AD). The screening of the journal articles was completed over 2 phases. Studies were initially excluded based on the content of the titles and abstracts followed by a full-text review. In the event of disagreement in the reviewer's decision, reviewers met to come to an agreed decision on the paper. Disparities in study selection were resolved by a 3rd member (KT).

*****INSERT TABLE 2 ABOUT HERE*****

2.3 Data extraction

One author (BN) extracted the data using a specifically designed standardised excel spreadsheet. General study information (i.e., author, year), subject characteristics (i.e., sample size, sex, age, body mass, height, sport, training status, performance level), training intervention characteristics (i.e., training methods, control group information, number of sessions per week, duration of training intervention, total amount of training sessions, training intensity, training volume, testing distances, testing equipment, training surface, other training, reported training-related injuries), and primary outcome measures (i.e., pre- and post-training intervention means and standard deviations) were extracted. All studies that included the time or velocity achieved from the initial start position (0m) to between >20m and ≤30m and 0m to >30m were categorised into the 0-30m and 0->30m subgroups respectively. The Vmax-phase subgroup included directly measured Vmax achieved or time to completion for distances >20m with a maximum intensity run-in distance of ≥20m before recording time (e.g., 20-30m or 30-40m). These outcomes aimed to identify distance specific changes, whilst representing the longer sprint distances (0 to 30-50m) performed by football code athletes and those commonly measured by researchers/practitioners. Descriptive information relating to the training activities performed in the studies was used to categorise each intervention into the training mode subgroups outlined in table 3. If the pre- and post-outcome measure data were not available from the tables or the result section, the data were requested from the author(s). If the authors did not have access to their data, data on outcome measures were extracted from figures using WebPlotDigitizer version 4.1 software (2018) (Version 4.1, WebPlotDigitizer, USA). Means and SD/SEM were measured manually at the pixel level to the scale provided in the studies figures.

INSERT TABLE 3 ABOUT HERE

2.4 Study quality assessment

The study quality assessment of the included studies was assessed using the same scale as McMaster et al., (54). This scale is designed to evaluate research conducted in athletic-based training environments from a combination of items from the Cochrane, Delphi and PEDRO scales. The methodological scale assesses the study in the following 10 domains: inclusion criteria stated, subject assignment, intervention description, control groups, dependent variables definition, assessment methods, study duration, statistics, results section and conclusions. Each domain was assigned a score of either 0=clearly no; 1=maybe; or 2=clearly yes. The scores were then summated to assess the total study quality out of a maximum of 20.

2.5 Data analysis and Meta-analyses

Data extracted from the systematic search were included in the meta-analyses. Improvements in sprint performance are typically identified by a reduction in time taken to cover a given distance or an increase in Vmax achieved for a given time point and or distance (55, 56). Therefore, pre- and post-time changes were reversed before conducting the analysis. This enabled both time and velocity changes to represent the same direction; thus, identifying a reduction in time or an increase in velocity for a given distance as a positive change.

A random-effects meta-analyses was performed by using Comprehensive Meta-Analysis Version 3.0 software (version 3, Biostat, Englewood, NJ, USA) to assess the magnitude of change in the outcomes across the relevant primary studies and to explore the effect of moderator variables on the variation among study outcomes (57). This included implementing two meta-analysis approaches 1) pre-and post-training within-group changes and 2) pairwise between-group effect differences designs. This approach provides an extensive review of all the available training intervention literature for developing sprint performance in football code athletes, including multiple research designs with and without sport only control groups. Overall summary estimates were calculated for each of the training type subgroups: primary, secondary, combined specific, tertiary, combined methods and sport only training (Table 3). A meta-analysis was conducted to identify the between-comparator group (e.g., primary vs. sport only, tertiary vs sport only) adjusted mean performance effects when a sport only comparator group was available. Combining a within-group pre-post change design and pairwise between-group differences enabled an evaluation of both high-quality control trial studies to evaluate training causality while also exploring the breadth of the available literature using a range of research designs.

Outcome measures were converted into the standardised mean difference (SMD) with 95% confidence intervals (CI) and were used as the summary statistic. The SMD represents the size of the effect of the intervention relative to the variability observed in that intervention. An inverse-variance random-effects model was used for the meta-analyses because it allocated a proportionate weight to trials based on the size of their individual standard errors and facilitates analysis while controlling for heterogeneity across studies (58). The inputted data included sample sizes, outcome measures with their respective standard deviations, and a correlation coefficient for within-subject measurements. These correlation coefficients (0-30m r=0.92, 0->30m r=0.92 and Vmax-phase r=0.95) were estimated from prior field testing. The SMD values were interpreted as <0.20 as trivial, 0.20-0.39 as small, 0.40-0.80 as moderate and >0.80 as large (59). A positive SMD indicates that the training intervention was associated with an improvement in sprint performance, while a negative SMD indicates a decrease in the respective performance outcome. Accompanying p values tested the null hypothesis that there was no statistically significant change in sprint performance regardless of the training method. Statistical significance was considered for $p<0.05$. Heterogeneity between trials was assessed using the I^2 statistic, moderate (>50%) to high values (>75%) were used to indicate potential heterogeneity sources (60). The I^2 statistic was supported by reporting the Tau-squared statistic and the Chi-squared statistic. Sensitivity analyses were used for each subgroup by repeating the analyses with each study omitted in turn; this would examine whether any conclusions were dependent on a single study.

Subgroup analyses were performed to 1) compare the within-group change in pre- and post- sprint performance and pairwise between-group effects from comparative trials and 2) evaluate the potential moderator variables. The moderator variables were determined a *priori*: sex (male vs. female), football code, playing standard (elite vs. sub-elite; [from Swann et al., 2016, the highest reported standard of performance (61)]), age category (senior [mean age ≥18yrs] vs. youth [mean age <18yrs]) and training phase (pre-season vs. in-season vs. off-season).

2.6 Evaluation of small study effects

Small study effects were explored through visual interpretation of funnel plots of SMD versus standard errors and by quantifying Egger's linear regression intercept (62) to evaluate potential bias. A statistically significant Egger statistic (p-value < 0.05) indicated the presence of a small study effect.

3 Results

3.1 Overview

Following the removal of duplicates, a total of 1,801 studies were found. The study selection inclusion criteria identified 60 studies for inclusion in the within-group change meta-analysis and 26/60 studies for inclusion in the pairwise between-group analysis (Figure 1). The 60 studies (34-36, 63-119) included multiple different research designs (with and without experimental control groups), providing 111 intervention groups and 27 sport only groups. Training groups were sub-grouped into six training classifications (sport only n=27, combined methods n=35, primary methods n=8, secondary methods n=9, tertiary methods n=59 and combined specific n=0) to differentiate between findings for distinct sprint performance outcomes (Table 3). The identified twenty-six studies compared a training intervention with a sport only (i.e., control) comparator groups (35, 36, 63, 69, 71, 73, 76, 79, 81, 83, 84, 87-89, 94, 97, 99-103, 106, 107, 112, 113, 118). This provided 41 eligible training groups for pairwise between-group comparisons (sport only training vs. combined methods n=9, primary methods n=3, secondary methods n=2 and tertiary methods n=27).

*****INSERT FIGURE 1 ABOUT HERE*****

Electronic Supplementary Material Table S1 (non-specific/tertiary, n=59), Table S2 (combined, n=35) and Table S3 (specific, n=17) present the individual training groups study descriptives, training intervention and sprint outcomes for the included studies. The 60 studies (34-36, 63-119) represented a total sample of 1,500 football code athletes with a mean sample size of 11.1±3.9 participants per training group. Fifty-six studies were conducted in males, three studies in female athletes (77, 99, 115) and one in mixed populations (102). The mean age of the participants included in the studies ranged from 11-26.8 years. The athlete populations ranged from sub-elite to elite (61). Collectively, the training intervention durations ranged from 3-22 weeks (7.4±3.1 weeks), with the intervention training frequency ranging between 1-4 sessions per week (2.1±0.6) over 6-32 individual sessions.

Studies were conducted in soccer (n=43), rugby league (n=4), rugby union (n=4), rugby sevens (n=3), American Football (n=1), Australian Football (n=1), and mixed football codes (n=4). No studies using futsal or Gaelic Football players satisfied the inclusion criteria. Studies were conducted in pre-season (n=21), in-season (n=26), off-season (n=3), and across pre-season and in-season (n=2). Eight studies did not report the phase of the season. Sprint assessment distances ranged from 22.9m to 50m; 0-30m (n=46), 0->30m (n=20) and Vmax phase (n=13). Timing devices included electronic timing gate systems (n=52), high-speed video cameras (n=3), radar measurement devices (n=2), 1080 sprint device (n=2), a digital timing device (n=1), a laser measurement device (n=1), kinematic measurement system (n=1) and a mobile application (mysprint; n=1).

Sport only training groups were described as some format of offensive or defensive match simulation and technical and tactical drills performed 2-10 sessions per week across 2-6 days per week lasting between 30-120min per session as well as some form of endurance training and 1-2 competitive or friendly games per week. Various methods of endurance training were described including simulated games performed in small-, medium- or large-sided games formats (e.g., 3 vs 3 to 11 vs 11), low-intensity aerobic conditioning, high-intensity interval training and recreational or cardiovascular activities (e.g., basketball, biking, running, aerobics). Sport only training was conducted in both pre-season and in-season periods over a duration of 6-16 weeks.

Specific sprint training groups performed sprinting, resisted and assisted sprinting and technical sprint drills completed as individual modalities and/or in combination (e.g., complex and contrast sets). The training was performed 1-3 days per week, with intervention periods lasting from 4-8 weeks (8-21 sessions). The primary sprint training methods included single set interventions ranging from 8-10 repetitions of short-distance (18.3-20m) sprints (160-183m session totals) or 4-6 repetitions of long distance (200m) sprints (800-1200m session total). Multiple set methods ranged from 2-6 sets of 2-8 repetitions of medium-long distance (30-50m) sprints (120-1200m session totals). One study performed submaximal sprint efforts (85%Vmax), involving 4-6 sets of 4 repetitions of long (50m) sprints (800-1200m session totals) (95). Resisted sprinting was performed as either a single set of 3-10 repetitions of short-distance (18.3-20m) sprints (60-200m session total) or multiple set methods, ranging from 2-7 sets of 3-5 repetitions of short-medium distance (5-40m) resisted sled sprints (130-455m session total). Resisted sprint loads ranged from light-very heavy loads (44). Loads were prescribed based on percentage body mass (BM) (i.e., 10-80%BM). Assisted sprinting methods involved both single and multi-set methods. The single set intervention included 1 set of 10 repetitions of short-sprints over 18.3m with a bungee cord assistive load @14.7%BM (183m session total; (115)). Multi-set methods ranged from 1-3 sets of 3 repetitions of medium distance sprints (40m) with towing eliciting a 0.5-1s faster 0-40m time using a sprint master towing device (120-360m session total) (93). The same study used a combined study arm using the same assistance load while also wearing a 10lbs weighted vest.

Tertiary sprint training groups consisted of strength, power and/or plyometrics training performed as individual modalities and/or in combination (e.g., complex and contrast sets). The training was performed 1-4 days per week, with intervention periods lasting from 4-22 weeks (8-32 sessions). Lower body strength training (e.g., squat, hip hinge and calf raise variations) ranged from moderate-supramaximal loads (55-110%1RM) with low-high volume training (e.g., 2-6 sets of 2-6 repetitions and/or 2-6 sets of 8-30 repetitions). Power sessions consisted of ballistic (e.g., squat jump) and Olympic weightlifting type exercises (e.g., clean/snatch derivatives) at low-heavy loads (15-80%1RM, to +30%BM) and velocity-based training using loads corresponding to the mass at which optimal power is produced (1-1.1x optimal power load). Volume ranged from 2-5 sets of 2-12 repetitions. Plyometrics sessions involved low-high intensity plyometrics (e.g., ankle hops to 50cm accentuated eccentric loading drop jump at +20%BM) for 1-12 sets of 4-20 repetitions (20-260 foot contacts session totals). The only type of surface identified was a grass surface. Several of the sessions were performed in combination with upper body training.

Combined methods training groups consisted of various formats of both specific sprint training (primary and/or secondary methods) and tertiary methods in combination (e.g., strength, power, resisted and unresisted sprint training). These were completed as individual modalities and/or in combination (e.g., complex and contrast sets). The training was performed 1-4 day per week, with intervention periods lasting from 3-15 weeks (6-22 sessions). Strength training ranged from moderate-supramaximal loads (70-120%1RM) with low-high volume (e.g., 2-6 sets of 2-6 repetitions and/ or 3-4 sets of 8-12 repetitions). Power training consisted of ballistic (e.g., squat jump) and Olympic weightlifting type exercises (e.g., clean/snatch derivatives) at light to heavy loads (20-86%1RM) and/or velocity-based training using loads corresponding to the mass at which optimal power is produced (1-1.1x optimal power load or 0.8-1.2$m{\cdot}s^{-1}$ loads). This also included medicine ball throws from 3-12kg. Volume ranges were from 2-6 sets of 2-8 repetitions per set. Plyometrics sessions involved low-high intensity plyometrics (e.g., ankle hops to 75cm hurdle jumps) 2-5 sets of

1-10 repetitions (9-250 foot contacts session totals). The only type of surface identified was a synthetic grass pitch. The specific sprint training methods included single set interventions ranging from 1-8 repetitions of short-long distance sprints (5-45.72m) or multiple set methods, ranging from 1-5 sets of 3-7 repetitions of short-medium distance (5-40m) sprints (30-800m session totals) from various starting positions. Resisted sprint loads ranged from light-very heavy loads. Loads were prescribed based on absolute loads (i.e., 10-30kg), percentage body mass (BM), i.e., 5-20%BM or reduction in Vmax corresponding with the additional resistance applied (10-60% reduction in Vmax). One training study used assisted sprints, involving 1 set of 5 medium distance sprints (40m) with 25m of each sprint including a 2% gradient decline (200m session total; (72)). Several of the sessions were performed in combination with upper body training.

3.2 Study quality

The scores for the assessment of study quality (54) are shown in Table 4, ranging from 11 to 20 with a mean score of 18±1.9, demonstrating high study quality. Items 2 (subjects assigned appropriately (random/equal baseline)), 4 (control group inclusion), and 9 (results detailed (mean, SD, percent change, effect size)) were the most decisive factors in separating the high-quality from the low-quality studies.

*****INSERT TABLE 4 ABOUT HERE*****

3.3 Meta-analysis

Individual study statistics can be seen in the Electronic Supplementary Material Tables S1-S3.

3.4 Standardised mean difference for 0-30m performance

For 0-30m performance, 103 within-training group effects were analysed from 45 original studies (34, 36, 63, 65-69, 71, 73, 75-79, 81, 82, 84-92, 94-105, 112, 114-119). Thirty-two training groups from 21 studies were eligible for a pairwise between-group analysis (sport only control vs.experimental) (36, 63, 69, 71, 73, 76, 79, 81, 84, 87-89, 94, 97, 99-103, 112, 118). Figures 2-3 show the SMD for each training type.

3.4.1 0-30m within-group changes

The sport only and primary methods training failed to show statistical significance for change in 0-30m performance. Significant performance improvements were observed in the combined and secondary methods training groups (moderate SMD) and tertiary methods (small SMD).
The combined, secondary and tertiary methods demonstrated a significantly larger training effect than sport only training. Only secondary methods reported a significantly larger training effect than primary training methods.

*****INSERT FIGURE 2 ABOUT HERE*****

3.4.2 0-30m pairwise between-group differences

The combined and primary training methods failed to show statistical significance to sprint performance changes compared to sport only training. Significant performance improvements were observed (large SMD) for the secondary and tertiary training groups compared with the sport only control groups. Between-experimental subgroups analysis failed to show statistical significance between training methods. Between experimental-subgroup analysis was not conducted on the primary or secondary subgroups with control groups as only two training groups were available.

*****INSERT FIGURE 3 ABOUT HERE*****

3.5 Standardised mean difference for 0->30m performance

For 0->30m performance, 43 within-training group effects were analysed from 18 original studies (35, 64-66, 72, 74, 75, 80, 83, 84, 93, 107-111, 113, 115). Eight training groups from 5 studies (35, 83, 84, 107, 113) were eligible for a pairwise between-group analysis (sport only control vs. experimental). Figures 4-5 show the SMD for each training type.

3.5.1 0->30m within-group changes

The sport only training, primary and tertiary methods failed to show statistical significance for change in 0->30m sprint performance. Significant performance improvements were observed in the combined and secondary methods training groups (small SMD). Between-subgroups analysis failed to show statistical significance between training methods. Between-subgroup analysis was not conducted on the primary training methods subgroup as only two training groups were available.

*****INSERT FIGURE 4 ABOUT HERE*****

3.5.2 0->30m pairwise between-group differences

Significant performance improvements were observed (large SMD) for the combined and tertiary training groups compared with the sport only control groups. Between-experimental subgroups analysis failed to show statistical significance between training methods.

*****INSERT FIGURE 5 ABOUT HERE*****

3.6 Standardised mean difference for maximum-velocity phase performance

For Vmax-phase performance, 31 within-training group effects were analysed from 13 original studies (34, 64, 69, 70, 85, 89, 106, 107, 109-111, 113, 115). Eight training groups from 5 studies (69, 89, 106, 107, 113) were eligible for a pairwise between-group analysis (sport only control vs. experimental). Figures 6-7 show the SMD for each training type.

3.6.1 Maximum-velocity phase within-group changes

The sport only training, primary, secondary and combined methods failed to show statistical significance for change in Vmax-phase performance. The tertiary training methods showed a significant moderate performance improvement. The tertiary training methods demonstrated a significantly larger training effect than primary training methods.

*****INSERT FIGURE 6 ABOUT HERE*****

3.6.2 Maximum-velocity phase pairwise between-group differences

The combined training methods failed to show statistical significance to sprint performance change to sport only training. Significant performance improvements were observed (large SMD) for the primary, secondary and tertiary methods training groups compared with the sport only control groups. Between-subgroup analysis was not conducted as the tertiary methods were the only training group where >2 training groups were available.

*****INSERT FIGURE 7 ABOUT HERE*****

3.7 Within-group change design vs. pairwise between-group effect

No significant difference was observed for the combined methods subgroups (all distance outcomes). Both significant (Vmax phase) and non-significant (0-30m) differences were found for the primary training between-subgroup analysis. The between-group effect from comparative trials was significantly larger for both the tertiary (all distance outcomes) and secondary methods (0-30m and Vmax phase).

*****INSERT TABLE 5 ABOUT HERE*****

3.8 Heterogeneity

The degree of overall heterogeneity was high for all outcome measures between studies I^2 (>75%).

3.9 Sensitivity analysis

Omitting each study separately identified the effect that each study has on the mean effect. This revealed minor changes only for the secondary training methods. These changes did not substantially impact the statistical significance of the overall mean effect. Sport only, combined, primary and tertiary training methods were sensitive to the exclusion of one or more studies independently and in turn, moderated the statistical interpretation of the results. Removal of one of the five 0->30m studies (35) from the sport only methods subgroup moderated the within-group change statistical significance from non-significant (p>0.05) to significant (p<0.05). Removal of one of the five 0-30m studies (89) and one of two Vmax-phase studies from the pairwise between-group differences (sport only vs. combined training methods) moderated the statistical significance from non-significant (p>0.05) to significant (p<0.05). Removal of two of the five 0-30m studies (69, 76) and one of three Vmax-phase studies (69) from the within-group change primary methods subgroup moderated the statistical significance from non-significant (p>0.05) to significant (p<0.05). Removing one of two 0-30m Vmax-phase primary methods subgroup studies (69) from the pairwise between-group differences (primary vs. combined training methods) moderated the statistical significance from non-significant (p>0.05) to significant (p<0.05). Removal of one of the eight within-group 0->30m studies (80) and one of the six Vmax-phase studies (70) from the tertiary training method subgroup moderated the statistical significance from non-significant to significant and significant to non-significant, respectively.

3.10 Evaluation of small study effects

Inspection of the funnel plots for the within-group change reported the presence of a statistically significant Egger's regression intercept revealed that there was evidence of small study effects for the 0-30m (intercept=9.36, 95% CI: 5.68 to 13.04; p<0.001) and Vmax-phase (intercept=11.38, 95% CI: -4.88 to 17.87; p<0.01). For studies included in the pairwise between-group differences comparison reported evidence of small study effects for the 0-30m (intercept=8.90, 95% CI: 4.22 to 13.21; p<0.001), 0->30m (intercept=6.60, 95% CI: -0.10 to 13.27; p=0.05) and Vmax-phase (intercept=15.83, 95% CI: -3.15 to 28.14; p=0.02). The SMD between pre- and post-intervention sprint performance was therefore not considered symmetrical, suggesting the presence of significant publication bias (120). However, there was little evidence indicating a small study effect for the within-group change in the 0->30m outcome studies (intercept=3.69, 95% CI: -1.90 to 9.28; p=0.19).

3.11 Moderator variables

Table 6 presents the subgroup analysis assessing potential moderating factors for sprint performance (0-30m, 0->30m performance and Vmax-phase). The between-subgroup analysis showed significant (p<0.05) differences for football code, age and phase of training, all moderated overall magnitude of training effects (either smaller or larger SMD). However, the between-subgroup differences were not consistent across distance outcomes. Both playing standard and sex consistently demonstrated no significant difference between subgroups.

*****INSERT TABLE 6 ABOUT HERE*****

4 Discussion

4.1 Overview of the main findings

Multiple training methods are recommended for improving medium-long distance sprint performance due to its importance in the football codes (32, 33, 40-49). This systematic review with meta-analysis is the first to 1) analyse the impact of different methods to enhance medium to long-distance sprint performance outcomes (0-30m, 0->30m and the max velocity phase) within football code athletes, and 2), identify how moderator variables (i.e., football code, sex, playing standard, age and phase of season) affect the training response. This review analysed 60 studies (34-36, 63-119), totalling 1,500 athletes sprint performance measurements, thus, providing the largest systematic evidence base for enhancing medium-long distance sprint performance over distances >20m, exclusively including football code athletes.

In summary, the meta-analysis of all the included studies showed enhanced sprint performance in the combined, secondary and tertiary training methods training groups. Combined and secondary methods showed small-moderate improvements in 0-30m and 0->30m performance. Tertiary methods showed small and moderate performance improvements in both 0-30m and Vmax-phase outcomes, respectively. Significant performance improvements (large SMD) were observed for the combined (0->30m), primary (Vmax phase), secondary (0-30m and Vmax phase) and tertiary methods (all outcomes) when compared with the sport only control groups. These findings support previous literature stating that football code athletes medium-long sprint performance can be enhanced concurrently alongside football code specific training (25, 41). Sport only training showed no significant change in medium-long sprint performance, suggesting such training alone is insufficient to improve performance. The significant differences between-group effect comparisons for studies with control groups and the within-group change consistently demonstrated a larger effect. Despite sprint measures over distance >20m being a proxy measure of Vmax improvements, changes in performance may not result exclusively from Vmax specific adaptations. Instead, performance changes in outcomes >20m may be attributed to either or both adaptations specific to the acceleration or Vmax phases. Between-subgroup analysis identified that football code, age and phase of training all moderated overall magnitude of training effects (either smaller or larger SMD). However, the between-subgroup differences were not consistent across distance outcomes. Soccer had a significantly greater increase in performance than rugby union, rugby sevens and American Football for 0->30m. American Football had a significantly greater improvement in performance than rugby union (0->30m). Youth athletes had a significantly greater increase in performance than senior athletes (0->30m). In-season performance changes were significantly greater when compared to pre-season and off-season in the 0->30m outcome only. Playing standard and sex consistently demonstrated no significant difference between-subgroups. The lack of consistency may suggest greater importance of other moderator variables, such as training and load prescription (e.g., mode, volume, intensity, and frequency), over the described individual population characteristics.

4.2 Summary of interventions to develop sprint performance

The 60 studies were categorised into five training modes resulting in 111 training groups (i.e., sport only, n=27; combined methods, n=35; primary methods, n=8, secondary methods, n=9; tertiary methods, n=59). Twenty-six of the sixty studies had sport only comparator groups (35, 36, 63, 69, 71, 73, 76, 79, 81, 83, 84, 87-89, 94, 97, 99-103, 106, 107, 112, 113, 118), which provided 41 training groups between-group effect comparisons (combined methods n=9, primary methods n=3, secondary methods n=2, tertiary methods n=27). No research met the inclusion criteria for the combined specific training methods group, which combines both primary and secondary training methods. These findings highlight the volume of tertiary method training studies and the reported gap in the available literature to support specific sprint training methods (primary, secondary and combined specific training methods) in football code athletes (33, 44). This also further supports the requirement for the within-group analysis, including a greater range of study designs given the small number of studies with a sport only control group available. The scarcity of specific sprint training method studies is most probably due to football code training typically consisting of tertiary training methods to develop multiple physical capacities (e.g., strength, speed, power) required within these sports. This is a strength of the current study, as previous reviews (32, 33) failed to include all training undertaken by the intervention groups within their analysis (e.g., primary or secondary training groups also completing tertiary training methods or vice versa (86, 116, 121, 122)).

The current degree of overall heterogeneity was high for all outcome measures between studies (I^2>75% (123)). Heterogeneity is to be expected in systematic reviews due to grouping of studies that are diverse, both clinically and methodologically (123). The high degree of heterogeneity reflects the diversity of the training effects presented. This is likely due to the wide variation in the intervention characteristics, including: training frequency (66, 68), intensity (34, 36, 73, 124), duration (64), volume (108) , other training completed (92, 94)), population characteristics (e.g., sex (102), baseline physical characteristics (76, 109), training experience (34, 68)) and sprint monitoring methods (e.g., start position, environmental factors (56)) and technology (e.g., equipment (69)). Therefore, these findings should be interpreted carefully as the variation of the effect sizes demonstrates that training response is highly individualised.

The study quality was high (18±1.9, ranging from 11-20) due to most studies providing clearly described research methodology, which enables practitioners and/or researchers to replicate or build on research findings reliably (125). A methodological study scale was used to evaluate research conducted in athletic-based training environments (54), showing that to increase the quality of future studies researchers should, randomise participants, include a control group and provide a detailed results section. The inclusion of detailed information on additional training conducted in applied settings is important to understand the training intervention undertaken and fully assess if there were any outside interactions with any adaptations seen following a training intervention (126).

Most training interventions reported positive effects on sprinting capabilities, which suggests that sprint performance outcomes can easily be improved with a variety of methods. However, this needs to be considered from the context of the literature base and the relative importance of phase-specific adaptations. Included studies represented both youth and senior athletes from elite and sub-elite cohorts, with the majority having limited previous systematic exposure to the intervention methods (e.g., (68, 69, 71, 75, 80, 87, 113)). Based on the dose-response relationship and the diminishing returns principle, athletes with a relatively low training age are more likely to have greater training response (127-129). However, as previously reported (33), this does not appear to be the case for the Vmax-phase or highly trained populations. Highly trained athletes have demonstrated that mean annual within-athlete sprint performance differences are lower than typical variation, or smallest worthwhile change, and the influence of external conditions (e.g., wind, temperature, altitude, timing methods/procedures (56, 129)). Inspection of the funnel plot and Egger's regression intercept identified evidence of small-study effects in the 0-30m and Vmax-phase performance outcomes. The SMD between pre- and post-intervention sprint outcomes were not considered symmetrical, suggesting the presence of significant publication bias. While publication bias towards studies reporting positive outcomes may be involved, another plausible explanation is the lack of a control group in many studies, as the results might have been affected by learning effects or the football code training in the intervention period.

4.3 Subgroup analyses of training methods

The principle of specificity (137, 138) was used to categorise the training intervention subgroups (i.e., sport only, primary, secondary, tertiary and combined). Primary methods present the greatest specificity by simulating the sprint movement pattern (130), while the secondary methods are less specific, involving overloaded sprinting actions. The tertiary training methods included strength, power, and plyometric training, which are considered the least 'specific' to sprint performance as these methods are commonly performed to target neuromuscular adaptations rather than simulating movement mechanics (131). The extent to which the method impacts and 'transfers' to sprint performance ultimately determine the quality of a training programme to improve athletic performance (132).

The underpinning factors to developing sprint performance appear to be consistent across sports (133-139). Practitioners can target the determinants of performance, such as optimising the sequencing of stride length and frequency, enhancing the athlete's physical capacities relative to body mass (e.g., lower limb force-velocity-power; stiffness) and increasing the mechanical effectiveness of force application (133, 135, 137, 139-144)). These methods provide practitioners with multiple methods of developing sprinting performance (129, 143, 145). Performance improvements result from specific transferable training adaptations typically categorised as neural or morphological (architectural or structural) factors (26, 145-148). However, training effects appear to be mode-specific with distance specific performance changes (e.g., 0-30m and 0->30m) associated with phase-specific adaptations (32). Although the factors underpinning sprint development are consistent, there are clear phase-specific differences in both kinetic and kinematic variables (26). The importance of mechanical variables appears to shift as sprint distance increase (e.g. greater association between theoretical maximal force generation in shorter sprints vs. greater associations in maximum theoretical velocity force can be applied in longer sprints (149)). Therefore, it is important to consider the phase-specific adaptations that may be present across medium-long distance sprint outcomes.

Despite researchers and practitioners typically using outcome measures over distances greater than 20m as a proxy measure of Vmax-phase capabilities; performance changes may be attributed to either or both adaptations specific to the acceleration or Vmax phases, not the Vmax-phase exclusively. This is evident as the Vmax-phase presented distinctly different performance changes to both the 0-30m and 0->30m outcomes. Although the acceleration and Vmax-phases are related (8, 131, 149-152), separate physical capacities and mechanical parameters determine sprint performance (27, 29, 128, 136, 139, 153-155). Research has demonstrated that football code athletes can attain Vmax-phase sprinting patterns at distances ≤20m (6-10, 29). Therefore, after 20m, there is likely an increasing influence of the Vmax-phase, with the time spent increasing with distance. Therefore, due to the sequential phases of sprinting both 0-30m and the 0->30m outcomes will be influenced by changes in the acceleration, with the 0->30m outcome influenced to a lesser extent (more time performing Vmax sprinting patterns). Whereas the Vmax-phase flying sprint split times and Vmax assessments do not include or include limited acceleration phase. Hence, it is important to emphasize, although, the sequential phases are related, different factors affect performance in each phase. Therefore, training protocols to develop each of these phases must also differ (33). This is evident in both the secondary and combined methods training groups. Hence, when including all studies both training methods presented a significant improvement in both 0-30m and 0->30m performance, whereas they produced non-significant trivial changes in Vmax-phase performance. Therefore, practitioners should also consider the mechanical and neuromuscular requirements that shift across the sub-phases (acceleration, maximal speed, and maintenance) of medium-long distance sprint outcomes and the implications these have for training phase-specific performance (26, 149, 153, 156).

4.3.1 Sport only training

Sport only training focuses on the development of technical and tactical performance within football and does not include any specific or non-specific sprint training. The meta-analysis showed sport only training groups did not significantly change sprint performance (35, 36, 63, 69, 71, 73, 76, 79, 81, 83, 87-89, 94, 97, 99-103, 106, 107, 112, 113, 118). Football code training is characterised by multidirectional and intermittent bouts of high-intensity running and sprinting interspersed between bouts of moderate and low-intensity activity (e.g., jogging, walking and repositioning (157-160)). Therefore, although football code training may involve athletes repeatedly performing short-sprints (e.g., 5–20m, 2–3s) during and in-between sport-specific actions (2, 23, 157, 158, 161); it most likely has limited or no very high-speed or sprint threshold running (159, 160, 162). Such training methods fail to meet the recommendations that athletes are exposed to multiple sprints where they maximally accelerate to achieve and maintain Vmax with complete recovery between efforts to effectively enhance sprint performance (129). Further explanations could include residual fatigue and the interference effect affecting maximal force and velocity outcomes within sport only practices (129, 163-165). Therefore, evidence suggests that sport only training alone is insufficient to improve medium-long sprint performance, and football code practitioners should be aware of this within their planning and delivery of training.

4.3.2 Primary methods

Primary methods simulate the sprint movement pattern (e.g., sprint-technique drills, stride length and frequency exercises, and sprints of varying distances and intensities). The combined exposure of large forces (>2xBM) produced over short ground contact periods (~0.08 to ~0.20s) performed at high movement velocities (7-10m·s^{-1}) while maximally sprinting results in both a coordinative overload and high neuromuscular stimulation (133, 135-137, 139, 154, 166). Therefore, exposure to maximal sprinting is expected to facilitate chronic physical adaptations and enhanced mechanical efficiency to improve sprint performance (132, 133, 135-137, 139, 166). However, no studies have measured chronic kinematic changes over distance >20m in response to primary training methods (no additional tertiary methods) to support their use in football code athletes (93, 106). Our findings suggest that primary training methods (69, 76, 77, 93, 95, 106, 115) may not significantly improve sprint performance, and in some cases, may impair performance. The primary methods within-group changes presented no significant change in sprint performance (i.e., 0-30m SMD = 0.20 [95 %CI=-0.01, 0.42], 0->30m SMD=0.06 [95% CI=-0.14, 0.25] and Vmax SMD=-0.07 [95% CI=-0.24, 0.10). This is further supported by the pairwise between-group comparisons (sport only vs. primary) confirming no significant difference in the 0-30m SMD = 0.36 [95 %CI=-0.36, 1.08] was evident. Despite the Vmax phase outcome reporting, the primary methods were superior (large SMD) to sport only training (SMD = 1.19 [95 %CI=0.21, 2.17] this difference reflects the maintenance of sprint performance rather than the reduced performances reported in the sport only groups (e.g., (69, 106)). The contradiction between our findings and previous reviews supporting the primary training methods is likely due to other studies misclassifying training methods by failing to include additional training (e.g., resistance training), most probably as part of their usual training programme (e.g., (38, 116, 167-170)). Therefore, previous review findings may support a combined approach of both specific and nonspecific training, not primary training alone (32, 33).

Football code athletes have high chronic exposure to short-sprints (<20m) with incomplete recovery between sprints as part of the demands of training and matches; therefore, replicating these exposures is unlikely sufficient stimulus for neurological or morphological adaptations (157-160, 171). Prescribing short-sprint repetition distances (e.g., 18.7-20m (69, 76, 115)) limits athlete exposure to sprinting at Vmax (typically achieved at >20m in football code athletes (8, 9, 27, 29-31)), performed at submaximal efforts (<95% Vmax (95)) and or with incomplete recovery (e.g., 2-3min between repetitions [<1-2 min·s of activity^{-1}]) for medium-long-sprints (e.g., 30-55m sprints, ~4-7s duration (77, 95, 106)). Furthermore, incomplete rest between sprint efforts may reduce maximal sprint intensity causing metabolic stress and reduction in energy substrates (172-174). However, it is worth noting that the removal of two studies (69, 76), which prescribed short sprints, would moderate the statistical significance for the (0-30m and Vmax-phase) outcomes from non-significant to significant. These findings contrast the findings in short-sprint performance, presenting that longer sprints and Vmax-phase outcomes may be more susceptible to performance changes from primary training methods when prescribed appropriately (25). Future studies should provide complete rest periods between maximal intensity sprints reaching and maintaining Vmax.

Running technique drills that simulate the sprinting action by isolating specific movements into more manageable components (129, 175) are a component of primary training. For positive reinforcement of the technique, sprinting biomechanics must closely resemble the action and develop the athlete's limiting factor(s) (130, 176). However, technique drills (e.g., A and B drills) are often performed at much slower velocities than sprinting, potentially not replicating sprinting from a kinematic standpoint (177). It has been questioned whether running drills have value, especially when performed incorrectly (178, 179). However, as with short distance sprint outcomes (25), no study has evaluated the effects of including/ excluding sprint technique drills in football code athletes, and often limited explanation of the training prescription is provided. Therefore, sprint training that addresses the magnitude and rate of force production on the ground and the mechanical efficiency (e.g., tertiary or secondary methods) may be more appropriate (179).

4.3.3 Secondary methods

Secondary training modalities apply overload to the sprinting action by reducing (e.g., resisted sprinting) or increasing the movement speed allowing athletes to reach supramaximal velocities (e.g., assisted sprinting). Across the 7 studies (67, 69, 75-77, 93, 115), findings showed a significant moderate within-group improvement in 0-30m (SMD=0.61 [95% CI=0.31, 0.91]) and small improvements in 0->30m (SMD=0.37 [95% CI=0.25, 0.50]) with no significant changes in Vmax-phase (SMD=0.07 [95% CI=-0.10, 0.23]). These findings are supported by the pairwise between-group analysis (sport only vs. control), confirming the effectiveness of the secondary methods (large SMD) in enhancing or maintaining medium-long sprint performance respectively compared to reductions sport only training groups (0-30m (SMD=2.68 [95% CI=1.65, 3.71]), and Vmax-phase (SMD=1.41 [95%

CI=-0.28, 2.53]). Training adaptations have been reported as velocity change specific (%Vmax increase vs. reduction (180)), with variation in distance specific improvements for secondary methods (i.e., assisted vs. resisted) (115). This is evident in both our findings and those of a previous review, reporting no significant improvements in Vmax-phase outcomes in secondary training methods (33). Hence, the improvements in 0-30m and 0->30m performance maybe a result of acceleration-specific adaptations reflected in short-sprint improvements included in the sprint outcome. The overload of the secondary training methods results in neurological or morphological adaptations allowing greater generation of ground reaction forces and improved mechanical efficiency to enhance performance (33, 44).

Resisted sprints (i.e., loaded sleds) have been shown to increase both stride length and stride frequency and acute increase in forward trunk lean (improved position to generate horizontal impulse) during sprints <20m in team sport athletes and university students (181-184). In contrast, assisted methods have demonstrated increases in stride length and decreased stride frequency in track athletes (33, 44). Whereas reduced ground contact times were reported in football code athletes (93). There are currently limited studies measuring chronic temporospatial changes in response to secondary training methods (no additional tertiary methods) to support these in football code athletes (93). Of the two overload strategies, resisted sprint training (67, 69, 75-77, 115) has received the greatest attention in the research in football code athletes despite significant improvements in both training methods (resisted (69, 75-77, 115), assisted (115) and a combination of both (93)). Currently, no study has reported a statistically superior training effect between assisted and resisted training modes. Hence, it is unclear which training mode is the most effective for developing sprint performance. Therefore, secondary training methods appear to be an effective method for coaches and athletes to improve 0-30m and 0->30m sprint performance outcomes. However, if the aim is to develop the Vmax-phase performance, then training strategies other than sled towing (e.g. weighted vests) may be needed to develop phase-specific adaptations. For example, vertical forces have a greater relative contribution to the Vmax-phase (135, 136). Acute kinematics differences suggest vertical force production when sprinting could be developed through undertaking training strategies utilising weighted vests by providing a greater load on the eccentric braking phase at the beginning of the stance phase (184, 185). Whereas sled towing is expected to provide a superior adaptation in horizontal force production (184, 186, 187). Further research is required to determine the optimal load, loading strategy and dose for performance enhancement, particularly for Vmax development.

4.3.4 Tertiary methods

Tertiary training methods represent a wide range of training methods (e.g. strength, power, plyometrics (32, 188)) which are commonly performed to target neuromuscular adaptations that determine sprint performance (e.g., force-velocity-power and force-velocity profile) rather than simulating movement mechanics (26, 129, 145, 149). Using the load-velocity relationship, the appropriate resistance (bodyweight or external loads) to limit either or both the maximum velocity and force at which the maximum effort will occur (189). Therefore practitioners are able to use force-velocity-power orientated exercises in isolation or in combination (e.g., high-force/low-velocity vs low-force/ high-velocity vs peak power load to target load specific adaptations (26, 129, 145, 149)).

Despite previous criticisms of tertiary training methods in the literature questioning the effectiveness for developing sprint performance, significant within-group moderate improvements were found for the 0-30m (SMD=0.38 [95% CI=0.23, 0.53]) and Vmax-phase outcomes (Vmax SMD=0.45 [95% CI=0.08, 0.81]). This is supported by significant findings in the pairwise between-group analysis (sport only vs tertiary) with performance improvements observed (large SMD) confirming the effectiveness of the tertiary training methods in enhancing medium-long sprint performance compared to sport only training (0-30m (SMD=1.44 [95% CI=0.95, 1.93]), 0->30m (SMD=1.05 [95% CI=0.59, 1.52]) and Vmax-phase (SMD=2.07 [95% CI=-0.95, 3.19]). No significant change was found for the 0->30m outcome when all studies were included (SMD = 0.22 [95% CI=-0.26, 0.70]). Therefore, phase-specific adaptations may be present. However, the presence of significant improvements in both 0-30m (likely a greater influence of the acceleration phase) and the Vmax-phase performance changes are likely a result of both acceleration and Vmax-phase specific adaptations. Research comparing the kinetic factors underlying differences between athletes with higher Vmax capabilities (sprinters) vs slower athletes (soccer players), found that at the same touchdown velocity, the sprinters attenuated the eccentric forces to a greater extent in the late braking phase and produced a higher antero-posterior component of force yet ground contact durations were similar across groups (27). Therefore, training methods such as strength, power or plyometrics training that increase an athlete's ability to produce sufficient vertical force, to withstand and reverse eccentric braking forces, and to generate high antero-posterior propulsive force may be required to enhance an athletes ability to accelerate more rapidly while also attaining a greater Vmax (27, 129). The improved physical capacities developed during tertiary training methods have previously been shown to manifest in significant improvements in sprint performance with associated reductions in contact time or changes in stride frequency and length (34, 106, 168, 169). Therefore, high correspondence likely exists between the larger ground reaction forces produced across medium-long distance sprints and the neural and morphological adaptations induced by these training methods (139). Hence, the lack of significance in the 0-30m outcomes are likely due to large significant reductions in sprint performance presented by Gabbett (80), moderating the statistical interpretation of the results. Therefore, supporting previous research (32), for the use of tertiary training methods (i.e., strength, power, and plyometric training) performed individually or in combination (e.g., strength power and plyometrics training) for improving sprint performance.

Considerations should be made when training for increased mass development often associated with tertiary methods, as an athlete gets heavier; they may not produce higher maximal force characteristics when normalised for body mass (131). Therefore, the force requirements in the stance leg increase with body mass to minimise the braking forces and maximise propulsive forces to attain Vmax, as does the aerodynamic drag resulting from a larger frontal surface area (131, 190). Hence, increases in body mass may be counterproductive for sprinting, at least when not moving an external mass (131).

4.3.5 Combined methods

Combined methods training includes both specific sprint training (primary and or secondary methods) and tertiary methods, recommended by researchers, sprint and football code practitioners to develop sprint performance (24, 32, 132, 191-193). This combination of both training methods enables practitioners to provide stimuli to develop both mechanical efficiency and the maximal physical capabilities of the lower limb concurrently (109, 168, 169, 194). Previous studies, combining specific and tertiary training methods, demonstrated significant improvements in physical capacities (e.g., force, velocity and power (36, 109)), as well as increased stride lengths, reduced stride frequencies and stance contact times (64, 168, 169). However, the changes in spatiotemporal variables are limited to short-distances with no significant changes presented in medium-distance sprints (e.g., stride length or frequency and contact or flights times (36, 64)). The findings of this review reported significant within-group moderate improvement at 0-30m (SMD=0.43 [95% CI=0.21, 0.65]), and small improvements in 0->30m (SMD=0.33 [95% CI=0.15, 0.51]) with no significant change in the Vmax-phase (SMD=0.05 [95% CI=-0.23, 0.34]). Pair-wise within-group analysis (sport only vs combined) reported significant performance improvements in favour of the combined methods (large SMD) 0->30m SMD=1.48 [95% CI=0.23, 2.72]). Interestingly, the 0-30m and Vmax phase contrast these findings, suggesting the combined methods were no more effective than sport only training (0-30m (SMD=0.60 [95% CI=-0.85, 2.04]), and Vmax-phase (SMD=-0.83 95% CI=[-4.33, 2.68]). Through sensitivity analysis, it appears the single study demonstrating a large reduction in sprint performance changes both the statistical significance and direction of the reported effect (89). The negative effects reported in this study have attributed to the interference of the volume of aerobic training and thus is an important consideration when attempting to develop medium-long sprint performance. As presented in secondary training methods, there appear to be phase-specific adaptations present with performance changes likely a result of acceleration-specific adaptations reflected in short-sprint improvements included in the sprint outcome. Despite presenting the significant training effects, each method presented different training methods (e.g., Electronic Supplementary Material Table S3). Therefore, combined specific methods appear to be an effective training method for football code athletes 0-30m and 0->30m sprint performance outcomes. However, if the aim is to develop the Vmax-phase performance, training strategies may be modified to develop phase-specific adaptations (e.g., increase vertical ground reaction in reduced stance phases). Further research is required to identify the optimal combination of exercises and training loads to improve phase-specific performances.

4.5 Moderator Variables

It is important to identify the moderator variables (i.e., football code, sex, age, playing standard, stage of the season) that may impact upon sprint training outcomes. Studies were not included in the analysis if the value used for subgroup analysis was not reported, failed to provide sufficient detail or did not match the appropriate moderator categories.

4.5.1 Sex

The meta-analysis of the intervention training groups found that both male and female football code athletes' sprint performance can be improved. However, the female improvement for the 0->30m and Vmax-phase outcomes were not significant. When comparing male and female athletes, there was no significant difference between the training effects. This should be taken within the context of the scarcity of the available information within female athletes training compared to males (195). The limited research comparing sex differences in training response in football codes athletes found no significant effect of sex on changes in sprint performance (102). Therefore, despite the demonstrated differences between physical characteristics (21, 131) and endocrine response (196) to training between males and females, there is currently no sufficient evidence to suggest practitioners should approach developing sprint performance differently based on an athlete's sex.

4.5.2 Playing standard

Both elite and sub-elite subgroups improved sprint performance. However, there was no significant improvement in sub-elite Vmax-phase performance. The between-group comparison identified no significant difference between the training effects for elite and sub-elite groups. Despite sprint performance differentiating between performance standards, (19-21), no study has explored whether sub-elite athletes are more sensitive to training than elite populations. However, research has demonstrated a decrement in the magnitude of the correlations with increasing levels of practice between sub-elite athletes' lower limb's neuromuscular maximal capabilities and the ability to generate force during sprinting compared to the in elite athletes (128, 149). Therefore, further improvements may be represented by the ability to effectively apply force into the ground at progressively increasing velocities (mechanical effectiveness) to achieve either or both a greater rate acceleration and enhanced Vmax performance. Hence for medium-long distance sprints, a greater focus on developing the mechanical capabilities contributing to the athlete's ability to generate propulsive impulse (force x time) and their application at higher velocities and decreasing ground contact times (i.e., mechanical efficiency, theoretical maximal horizontal velocity and maximal power) is required (145, 149). This theoretically may be achieved by using resisted sprints that enable athletes to apply force at high velocities (low loads or assisted sprinting), by training at loads that correspond with optimal load for maximal power as well as low load (BM) or assisted horizontal or vertical jumps (145). However, further research is required to demonstrate the effectiveness of these training strategies. Therefore, despite the demonstrated differences between physical characteristics between elite and sub-elite athletes (131) when considered independent of training status, there is insufficient evidence to suggest practitioners should approach developing sprint performance differently based on athlete's playing standard within the football codes.

4.5.3 Age

Both senior and youth cohort subgroups sprint performance was enhanced following training interventions apart from the youth Vmax-phase. Between-group comparisons identified youth athletes enhanced sprint performance more than senior athletes at 0->30m, which supports previous research stating that younger athletes typically have a greater training response compared to older counterparts (80). Factors such as chronological age may have moderated the training effects of the tertiary training methods in male youth athletes with a greater training effect in younger (<15yrs) vs. older (<18yrs) athletes (80). Youth athletes experience multiple morphological and neural changes as a result of growth and maturation (197), which has implications influencing sprinting performance changes (48, 50, 198). The stage of maturation has been shown to moderate the training effect with youth athletes training pre-peak height velocity, presenting lower improvements than mid- and post-peak height velocity (48, 50). Changes in youth cohorts may have been affected by pre-pubescent athletes and in-effective training exposures (85), which was not considered in the current analysis. These training effects suggest that within youth athlete's coaches should take into consideration chronological and maturational age, and increased baseline performance levels and greater training experience (80, 199). However, further research is required to understand sprint performance outcomes by age, which could include maturity grouping.

4.5.4 Sport

All sprint performance outcomes were improved in the soccer subgroup. Both rugby union and American Football presented significant improvements in 0-30m and 0->30m respectively. There was no significant improvement found in the rugby league, rugby sevens and Australian rules football. Football codes training subgroups with limited representation in the literature (1-2 training groups for a given distance outcome) were not considered for subgroup analysis (e.g., 0-30m rugby sevens [n=1] (78)). Despite differences in physical characteristics (128, 131) and movement demands (157, 158), there were limited between-subgroup differences. The between-group comparison showed that soccer had a significantly greater increase in performance than rugby union, rugby sevens and American Football (0->30m). American Football had a significantly greater improvement in performance than rugby union (0->30m). No significant differences were found between the training effects for the football code subgroups for the Vmax-phase outcome. Although several factors may have contributed to the significant differences (e.g., training content, duration frequency) the greater training experience to various forms of resistance training in the rugby codes and American Football (e.g., ≥2years systematic resistance training (64, 72, 98, 116, 117, 200)) may have resulted in lower morphological or neurological adaptability to the training stressors resulting in lower training responses when compared to the lower training experienced soccer subgroups (129, 131). However, there is insufficient literature to demonstrate the between-subgroup differences across all sprint performance outcomes, and it is currently unclear whether these are specific to training methods or distance outcomes. No study has compared the difference between training effects between football codes implementing matched training interventions in football code athletes on sprint performance. Therefore, there is insufficient evidence to support coaches adapting sprint training methods based on football code.

4.5.5 Season

The in-season and off-season subgroups presented significant improvements in 0-30 and 0->30m, despite practitioners typically having less time available to develop physical or movement capacities during the in-season and offseason periods (51). Whereas pre-season subgroups only significantly enhanced 0-30m performance. There was no significant improvement in the Vmax-phase at any of the phase of the season. It is generally reported that fitness improvements are observed in the preseason, with subsequent stabilisation of such fitness variables in-season (201). Consequently, higher benefits are expected in trials performed during the preseason period compared with in-season (202, 203). The between-group comparison found significantly greater improvements in-season compared to pre-season and off-season in the 0->30m outcome only. Therefore, with appropriate prescribed training methods, 0-30m and 0->30m sprint performance can be enhanced in-season. The 0->30m pre-season subgroup is sensitive to the large reduction in training performance presented by Gabbett (80), hence the lack of significant improvement. The Vmax-phase appears to present greater resistance to change based on the current training programmes. No study was included that has compared the difference between training effects between the phase of the season, implementing matched training interventions in football code athletes on sprint performance. Therefore, despite the differences in training demands between training phases, there is insufficient evidence to support coaches adapting sprint training methods based on the phase of the season.

4.6 Limitations

Whilst this study represents the largest systematic review and meta-analysis of medium-long-distance sprint performance, limitations exist. Firstly, this review classified training into groups (i.e., sport-only, primary, secondary, tertiary, combined and combined specific methods), which improves on previous classifications (32, 39) but also fails to consider the complexity of sprint performance development within the training prescription, the population and assessment methodologies. The broad within-group change approach taken was used to review all available literature; however, this method represents a suboptimal method of exploring training causality while also providing additional areas of bias to the interpretation (e.g., regression to the mean, (204)). However, we attempted to address this by combining a within-group pre-post change design and a pairwise between-group design enabling an evaluation of both high-quality control trial comparisons and to explore the breadth of the available literature using a range of research designs. Despite the important influence of prior training status and physical capacities (127-129), including this as a moderator, was not possible due to several reasons. These included: 1) most studies fail to report physical capacity and/or training experience within their descriptive statistics; 2) those that do, present a lack of consistency of how they are reported, and the testing methods used; and 3) studies are often limited to years of football code specific training or resistance training with little consideration on how the stimulus was provided. Therefore, the level of detail to fully understand sprint development is lacking, but this is difficult in the context of understanding sprint development and the multiple factors that interact. However, the review attempted to analyse several moderator variables (i.e., football code, sex, playing standard, age and phase of the season), highlighting a limitation that most research is undertaken using parallel group trials within male, soccer athletes involving mainly tertiary training methods. Therefore, research including randomised control trials across the football codes, female cohorts, which utilise multiple training methods are limited, which may impact the meta-analysis and moderator variable analysis and subsequent interpretation. While the limitations above exist, the information gathered from the current review with meta-analysis may support practitioners to use evidence-informed decisions when organising and evaluating training.

4.7 Future Research Directions

This review has presented similar research directions to that presented in short-sprint training literature as the limitations are consistent across all outcomes (25). Where possible future research should conduct high-quality research designs (e.g., randomised control trials) to expand and reaffirm the current findings whilst addressing the multiple gaps in specific populations. Research is required to examine the training effects in football codes outside of soccer (e.g., rugby codes, American, Australian rules, Gaelic Football and futsal), in world-class and successful elite athletes, trained populations with systematic training exposures, youth athletes of various growth and maturational statuses and female athlete cohorts. It is worth highlighting although there are several reported effective training methods it may be inappropriate to try to define the best methods for enhancing sprint performance in football (e.g., exercises, set and rep schemes). Instead, the integration of different methods based on the training background, individual requirements and their progression over the training process needs to be further analysed to inform the optimal stimulus and organisation of training. It is essential that future research design includes pairing subjects based on resistance training experience and/or physical capacities (i.e., lower limb force characteristics) to establish a greater understanding of whether training changes and adaptations are dependent upon these variables. Both researchers and practitioners should consider the combined modelling of velocity-time curves with the assessment of kinematic and kinetic changes performed at more frequent intervals. This would enable practitioners to isolate and confirm a time course of adaptations and the underlying causes to changes in performance (21, 128, 149), whilst also reducing the limitations associated with pre and post sprint times or velocities (55). Due to their respective importance in the football codes, future research should explore the development of repeated sprint ability and non-linear sprint outcomes providing practitioners with a more comprehensive overview of developing athletes sprint characteristics.

Previous research has identified that the majority of elite sprint and football code coaches report utilising and advocating an integrated approach using the combined training methods approach (24, 32, 132, 191-193). This is performed both individually or in separate sessions and combinations (e.g., complex or contrast sets) enabling the development of multiple physical capacities and skills simultaneously (24, 32, 132, 191-193). Therefore, further research would be better suited to manipulating the combinations, sequencing and loading parameters of combined specific and non-specific methods to enhance sprint performance longitudinally as ultimately within the football codes combined training is implemented. This should be combined with methods of profiling that allow optimisation and individualisation of training exposures (e.g., (149, 188, 205-207)), which may reduce the variability in performance change (188). While exercise specificity is certainly an important principle when developing a training program, it is only one of several principles that will influence the effectiveness of the program. Therefore, future research should continue to explore within and between-subgroups the effects of overload, variation, reversibility and the effect on sprint performance change (26). Furthermore, this needs to be supported with determining the minimal and optimal training doses to retain and develop sprint performance in football code athletes. This will directly influence practitioner's organisation of training and the prescribed loading variables.

5 Conclusions

Establishing the most effective methods to improve medium-long performance outcomes is an important consideration for practitioners working across the football codes. This study represents the first systematic review and meta-analysis of sprint performance development using medium-long distances outcomes that includes all training modalities, while exclusively assesses within and across football code athletes. The results shows that medium-long sprint performance outcomes can be enhanced through secondary (i.e., resisted or assisted sprinting), and combined (i.e., primary or secondary and tertiary training methods) (0-30m and 0->30m) and tertiary training methods (0-30m) training modes. In addition, tertiary training methods were the only method to enhance Vmax-phase performance significantly. Performance changes in outcomes >20m may be attributed to either or both adaptations specific to the acceleration or Vmax phases, and not Vmax exclusively. Despite this, when comparing training typology, no individual mode was found to be the most effective. However, both sport only training and primary training methods appeared to be insufficient to develop medium-long sprint performance outcomes. Moderator effects, although not mode-specific, suggest that there is not a consistent effect of age, sex, playing standard and phase of the season on sprint performance change across outcomes. Regardless of the population characteristics, medium-long sprint performance can be enhanced by increasing either or both the magnitude and the orientation of force an athlete can generate and express in the sprinting action. These findings present practitioners with several options to suit their programme to enhance medium-long sprint performance.

Declarations

Ethics

Approval was obtained from the ethics committee of Leeds Beckett University. The procedures used in this study comply with the ethical standards of the Declaration of Helsinki.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Authors' contributions

All the authors contributed to the manuscript, including the conception and design of the study, analysis and interpretation of the data, drafting and critically revising the manuscript, and approval for publication. All authors read and approved the final manuscript.

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