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The effectiveness of nutrition education programmes on improving dietary intake in athletes: a systematic review

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Abstract
Nutrition education programmes for athletes aim to enhance nutrition knowledge and more importantly support positive dietary change to enhance performance, health and well-being. This systematic review assessed changes in the dietary intakes of athletes in response to nutrition education programmes. A search was conducted which included studies providing quantitative dietary intake assessment of athletes of any calibre aged between 12 and 65 years in response to a nutrition education programme. Standardised differences (effect sizes) were calculated (when possible) for each dietary parameter. The search yielded 6285 papers with twenty-two studies (974 participants (71·9 % female)) eligible for inclusion. Studies described athletes competing at high school (*n* 3) through to college level or higher (*n* 19). Study designs were either single arm with an intervention-only group (twelve studies; *n* 241) or double arm including an intervention and control group (ten studies; *n* 689). No control groups received an alternative or 'sham' intervention. Face-to-face lectures (9/22) and individual nutrition counselling (6/22) were the most common education interventions. Non-weighed, 3-d diet records (10/22) were the most frequently utilised dietary assessment method. Although 14/22 studies (*n* 5 single and *n* 9 double) reported significant change in at least one nutrition parameter, dietary changes were inconsistent. Poor study quality and heterogeneity of methods prohibit firm conclusions regarding overall intervention success or superior types of educational modalities. Of note, carbohydrate intakes 'post-intervention' when assessed often failed to meet recommended guidelines (12/17 studies). Given the substantial investment made in nutrition education interventions with athletes, there is a need for well-designed and rigorous research to inform future best practice.

Key words: Athletes: Nutrition education programmes: Dietary intake

Nutrition education interventions aim to help athletes align their dietary intake with current sports nutrition guidelines[1,2]. These interventions, incorporated into many elite institute, professional or collegiate sports programmes, vary widely from individual consultations to group education; some incorporate practical skills such as cooking or shopping[2]. Despite the time and cost associated with athlete education, there is limited information on how these nutrition interventions influence dietary intake. A number of reviews have evaluated the level of nutrition knowledge in athletes[2,3], and one published recently also reports on how this improves with nutrition education[4]. Generally, the level of athlete nutrition knowledge varies widely amongst athlete groups[2,3], but improves, at least in the short term, even after brief nutrition education interventions[4]. However, due to the wide range of knowledge assessment tools with limited validation, the authors were unable to identify the most effective nutrition education modality to improve nutrition knowledge in athletes[4].

Although it is often assumed that greater nutrition knowledge results in better dietary intake, evidence suggests other factors (e.g. taste, cost and convenience) are equally important[5]. Athletes may fail to meet their dietary intake due to the challenges in navigating specific barriers such as available time for food selection and preparation due to high daily training commitments, suppressed appetite between training sessions, food culture and traditions unique to their sport, religious or environmental considerations and the body composition and physique requirements required for success[1,2]. Observations made by coaches and sports dietitians indicate that athletes who possess confidence in their nutrition knowledge are more likely to

Abbreviations: EER, estimated energy requirement; ES, effect size; RDI, recommended dietary intake.

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incorporate this knowledge into their lifestyle by choosing appropriate foods to match their sport[1,2]. However, the effectiveness of different types of nutrition education interventions to promote change in the dietary intake of athletes has yet to be evaluated.

Therefore, the primary aim of this systematic review was to investigate the effectiveness of nutrition education interventions on change in dietary intake in athletes. The secondary aim was to compare the effectiveness of different education delivery modalities (e.g. group *v.* individual or in-person to virtual education modalities). Given the substantial professional and institutional investment in nutrition education for athletes, a comprehensive evaluation regarding its effectiveness to modify dietary intake is relevant to informing future best practice.

Methods

Search strategy

The systematic literature search to identify studies was conducted by one researcher (A. B.) from the earliest record until June 2019. Databases searched included PubMed, Embase, CINAHL and SPORTDiscus (EBSCOHost) using key words and controlled vocabulary, 'athletes', 'sport', 'nutrition', 'diet', 'food', 'education*', 'programs*', 'counsel*', 'health education', 'intervention', 'strategy*', 'curriculum', 'lesson*', 'class', 'workshop*', 'program evaluation', 'dietary intake', 'energy intake', 'energy balance', 'behav*', 'feeding behavior', 'intake*', 'consumption', 'habits', 'patterns', 'practices', 'dietetics', 'food habits', 'caloric intake'. The full electronic search strategy is presented in online Supplementary Fig. S1. The search strategy was complemented by a hand search of studies referenced in similar reviews and included studies. This systematic review was registered on Prospero (CRD42018083952) and reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[6].

Eligibility criteria

Eligible study designs included randomised controlled trials, quasi-experimental and pre-post intervention studies. Abstracts and studies not reported in English were excluded. Studies of athletes, male and female aged between 12 and 65 years from all sports, and athletic levels were eligible for inclusion. Interventions including individual/group counselling/education, in-person or virtual (e.g. online/DVD) modalities were eligible if the primary outcome, change in dietary intake (energy, macronutrients, micronutrients and/or food groups, diet quality/index) was reported quantitatively.

Selection of studies and data extraction

After the search was conducted and duplicates removed, manuscript titles and abstracts were screened independently by two authors (A. B. and R. T.). Disagreements were resolved via discussion with a third author (G. C.). Full texts of all potentially eligible studies were reviewed independently by two authors (A. B. and R. T.). After identification of eligible full-text articles, data were extracted in duplicate (A. B. and R. T.). When relevant, paper authors were contacted (A. B.) and requested to supply additional/missing information. A computer program (WebPlotDigitizer, version 3.9) was used to calculate the mean and standard deviation of data reported in figures[7].

Nutritional information extracted pre- and post-intervention included mean energy (kJ), macronutrient (g), micronutrient (mg/μg), food group[7] and KIDMED diet quality/index (score of +1 or −1 totalling to a maximum 12)[7]. All nutrients were converted to SI units if reported otherwise. To manage table size in this review, only the micronutrients Fe and Ca were tabulated. Changes to other micronutrients were discussed only in the text. To compare changes, within- and when relevant, between-group (double-arm studies) effect size (ES) was calculated when relevant data (mean, SD or SEM) were provided. The Hedges' *g* (random model) ES was calculated using extracted data (mean, SD, sample size) in the Comprehensive Meta-Analysis version 2 software (Biostat, 2005), and were considered trivial (0·0–0·19), small (0·2–0·49), moderate (0·5–0·79) or large (≥0·8)[8].

Calculation of energy, macronutrient and micronutrient values across studies

To assess the adequacy of reported dietary intakes, the recommended food group or recommended dietary intake (RDI)/RDA guidelines specific to the country were used, and for studies using diet quality/indexes, the recommended ranges for these parameters cited in the paper (a sixteen-item Mediterranean diet quality index). To assess the adequacy of energy intake, the types of methodology used to determine the estimated energy requirement (EER) of the participants could range from published energy requirement algorithms, general population energy requirement recommendations for 'active' or 'very active' individuals, or literature reported values for the sport/activity.

The classification of adequacy for macronutrients varied depending on the specific guidelines used in the paper. Historically, scientific opinion on this ranged over the period of time the studies were conducted, initially being recommended as a proportion of daily energy (protein 10–15 %; fat 20–30 % and carbohydrate ≥50–60 % of daily energy intake), later recognition that g/kg per d recommendations were more appropriate (protein 1·0–2·0 g/kg per d and carbohydrate 3–12 g/kg per d[9]). Where possible, g/kg per d calculations were undertaken if not reported in the paper to assist in evaluating the appropriateness of the older, percentage of energy recommendations. Micronutrient adequacy was based on the respective country RDI/RDA values. Historically, mean intakes which did not meet the RDI/RDA, but were a set proportion ranging between 70 and 100 % of the RDI/RDA for micronutrients were reported as 'likely' to be adequate in older nutrition literature, although this is not an established way of reporting dietary adequacy.

Quality assessment

Study quality was independently assessed in duplicate by three researchers (A. B. all papers, H. O. and R. T. shared) using a modified version of the Downs and Black risk of bias rating tool[10]. The original tool consists of twenty-seven items that examine data reporting, external and internal validity, including bias and statistical power. In single-arm study designs, twenty of the twenty-seven items that logically applied were used. In double-arm study designs, twenty-four items were used. Item 18 addressed the validity and reliability of the tools used to measure dietary intake. This item was assessed as two parts as previously described by Spronk *et al.*[5], where one point was awarded for appropriate choice of dietary method and another point for appropriate application. This approach was adopted with consideration of items 7·2–7·5 in the Academy of Nutrition and Dietetics Quality Criteria Checklist to accompany the Downs and Black tool and allowing for clarification when assessing quality ratings. Downs and Black score ranges were provided with corresponding quality levels based on the scoring methodology of the Downs and Black checklist. Quality levels for single-arm studies included: excellent (20–21), good (15–19), fair (12–14) and poor (<12) and for double-arm studies excellent (23–25), good (18–22), fair (14–17) and poor (<14). The maximum scores were 21 and 25 for single-arm and double-arm studies, respectively. Disagreement between authors was discussed to achieve consensus.

Results

Literature search and study selection

A total of 8004 articles were identified through the database search. After removal of duplicates, 6285 articles remained. Screening by title and abstract identified thirty-six articles for full-text review. After evaluation against inclusion and exclusion criteria, twenty-one articles were eligible for inclusion (Fig. 1). One additional article was identified by hand-searching references of included papers.

Study characteristics

Study characteristics were summarised into single-arm (intervention group only) and double-arm (intervention and control groups) studies (Table 1). The sample size across all studies ranged from 7 to 210 athletes (80·5 % female). Studies were conducted in the USA (*n* 14), Europe (*n* 5), Iran (*n* 1), Malaysia (*n* 1) and Brazil (*n* 1). The majority of studies involved mixed sports (*n* 9), with one of these mixed sport studies involving two population groups (mixed sport and ballet dancers). Team sports were represented in seven studies including volleyball (*n* 3), soccer, baseball, softball and handball (*n* 1 for all). Individual sports included swimming, ballet, track and field, canoeing and wrestling (*n* 1 for all). The mean age of athletes across all studies was 19·8 years. Athletic calibre included high school (*n* 3 studies), collegiate (*n* 4 studies), state (*n* 1 studies), national (*n* 10 studies) and international (*n* 4 studies) levels. Two studies involved athletes with physical disabilities[11,12].

Intervention characteristics

Nutrition education modality. Various nutrition education modalities were utilised across the twenty-two included studies. Face-to-face group lectures (*n* 8 studies) and individual nutrition counselling (*n* 6) were most commonly used. Other modalities included group workshops/activities (*n* 4) or mixed methods (*n* 5), including lectures and handouts or lectures and individual counselling.

Nutrition education topics. Half of the studies (*n* 11) incorporated a combination of nutrition topics including energy, macronutrient, micronutrient and hydration principles; meal frequency and timing; and supplement use. Other topics incorporated food groups and dietary guidelines (*n* 2), nutrient recommendations (*n* 1), general sport nutrition principles (*n* 1), Fe (*n* 1), Mediterranean diet principles (*n* 1), and individual nutrition plans or weight control strategies (*n* 3). Self-efficacy, social cognitive or cognitive behavioural theory concepts to assist the athletes to make dietary change were included in 6/22 studies[13,14].

Duration and frequency of nutrition education. The nutrition education interventions ranged from 2 to 39 weeks in duration, with two studies (one single-arm, one double-arm) incorporating a follow-up period (6–16 weeks) and reported retention of dietary changes[13,14]. One study assessed athlete dietary intake changes across two seasons, with the education delivered during the second season, however failed to describe the duration and frequency of the education programme[15]. Session number varied from three (3/22 studies), 4–7 (13/22 studies), to more than seven (6/22 studies) sessions across the intervention period. Session duration ranged from 10 to 120 min with total intervention time ranging from 60 to 720 min.

Nutrition education facilitator. Most of the interventions (17/22) were delivered by a qualified (or student) nutrition professional with expertise described as, ‘dietitian’ (*n* 10), ‘sports or performance nutritionist/dietitian’ (*n* 4), ‘nutrition specialist/professional nutritionist’ (*n* 2) and student dietitian (*n* 1). The remaining studies (5/22) failed to report facilitator expertise[12,16–18].

Diet methodology characteristics

Most studies (15/22) assessed dietary intake twice, immediately pre- and then post-intervention, with some (5/21) studies also conducting assessments during the intervention (data not extracted). Two studies did not disclose the number of dietary intake assessment sessions but did present pre- and post-intervention results[15,19]. All studies utilised a valid diet method to collect nutrient intake; however, only 10/22 studies appropriately applied the methodology (i.e. appropriate sample size, population, duration, frequency and nutrients assessed)[15,19–21].

Study quality

Methodological quality had a mean score of 12/21 (range 7–15) for single-arm studies and a mean score of 15/25 (range 11–20) for double-arm studies, representing poor study quality and fair study quality for single- and double-arm studies, respectively (online Supplementary Tables S1 and S2). Most reported their aims (21/22 studies), main outcomes (18/22 studies), described the main findings (19/22 studies) and used appropriate statistical tests (15/22 studies). The lowest ratings were for the recording of compliance to the education intervention and collection of dietary intake (5/22 studies). Ten of the studies appropriately

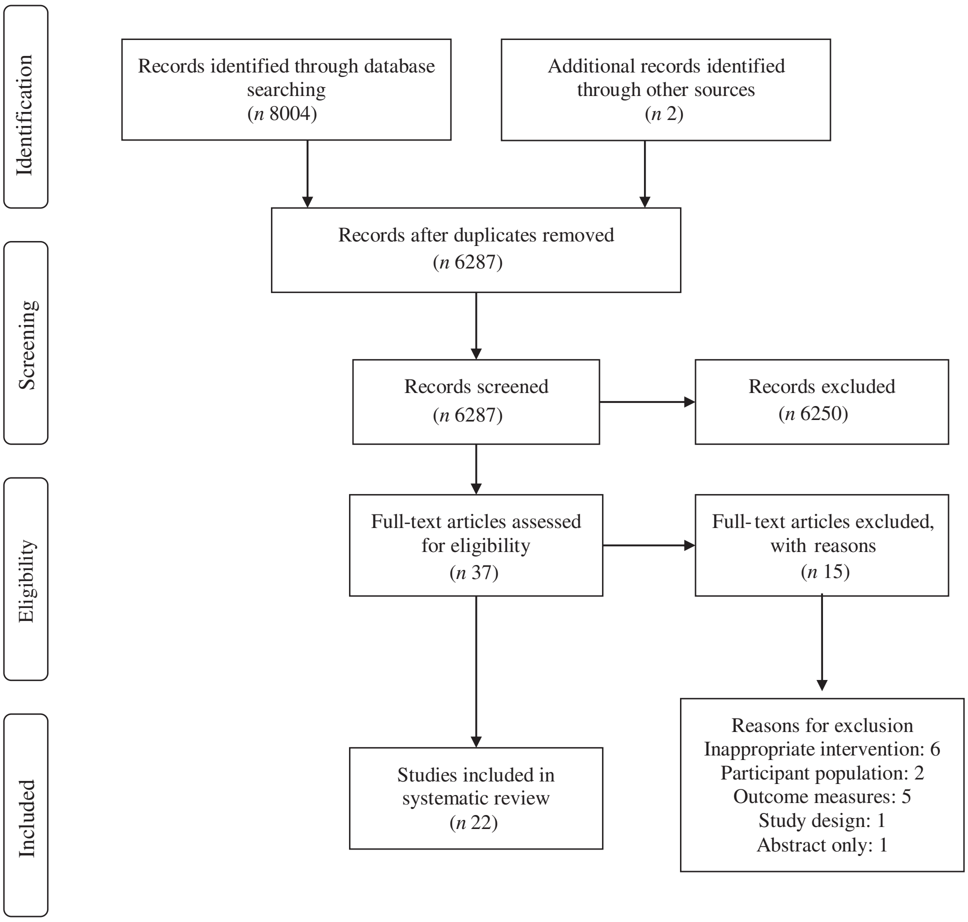

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart.

applied the dietary methodology with limitations in application mostly due to small participant numbers and inappropriate measurement and number of collection days for specific micronutrients. For example, Fe intake was reported after only 3-d of measurement in a food diary that requires up to eleven recording days[22].

Single-arm studies dietary outcomes

The single-arm studies (*n* 12) investigated the within-group changes in dietary intake pre- and post-nutrition intervention (Table 2). Of these studies, 9/12 reported changes in energy intake and 10/12 changes in macronutrients using predominantly 3-d diet records (*n* 6 studies), with a smaller number using 7-d diet records (*n* 1 study), 24-h recall (*n* 2 studies) or 72-h recall (*n* 1 study). Micronutrient intake was reported in 4/12 studies using predominantly 3-d diet records (*n* 3 studies) and one using 24-h recall (*n* 1 study). In 3/12 single-arm studies, food group intake was assessed[23]. Adherence to the Mediterranean diet using a diet index (KIDMED) was assessed in 1/12 studies[23].

Baseline dietary intakes did not always meet the nutrition targets identified by the researchers which were guided by their country's RDI/RDA or relevant sports nutrition literature at the time. In the case of energy, a range of methods were used to identify the appropriate EER for the athlete population investigated. This included the use of general population-based energy requirements typically identifying a range of suitable energy intakes for 'active' or 'very active' individuals. Other studies used algorithms (e.g. Harris–Benedict or Nelson equations) or sport-specific energy requirements reported in the literature to calculate the appropriate level of energy for the study population (based on age, sex, weight and height). Training loads of participants were only detailed in 2/9 studies assessing energy intake, contributing to the poor quality of studies since training information is essential to evaluate athlete energy requirements[9].

Few (2/9) single-arm studies that assessed energy intake reported this to be within the researchers' targeted EER at baseline[21,24]. Of those studies identified as having a low mean participant energy intake at baseline, 6/7 reported a significantly higher post-intervention energy intake (ES 0·4–2·3; $P \leq 0·05$), with only one[25] falling within the researchers' identified EER. The ES ranged from small to large. It is relevant to note that the study by Łagowska *et al.*[25] involved both ballet dancers and female-athlete sub-groups, and although both observed significant increases and large ES, only the female-athlete sub-group met energy intakes within researchers' range post-intervention (ES 1·0–2·3; $P \leq 0·001$). Conversely, the remaining study (1/7) with low baseline energy intake reported a close to significant decrease further below the researchers identified EER post-intervention (ES −0·2; $P = 0·05$)[14]. All 7/9 studies where authors

Table 1. Participant, intervention and dietary analysis characteristics of included studies: single-arm and double-arm studies
(Mean values and standard deviations)

	Participants				Intervention				Dietary analysis	
		Age (years)								
Study	*n* (sex)	Mean	SD	Population; calibre	Delivery style	Duration and frequency	Nutrition curriculum	Facilitator	Dietary analysis method	Times administered
Single-arm studies										
Collison *et al.*[14]	26 (F)	19·4	1·2	Volleyball, field hockey and tennis; NR	Workshop	2/52 (1× weekly)	Energy; macro; micro; fluid; weight control; bone health; label reading	Dietitian	3-d diet record	Pre-intervention, post-intervention, 3 months post-intervention (retention)
Kandiah[12]	10 (M)	24	2·12	Track and field; elite	Weekly newsletters, telephone counselling	16/52 (8× sessions)	Fat; cholesterol; influence of animal fat; macro and micro related to athletic performance; food sources; serving sizes; fluids	NR	3-d weighed food record	Random throughout intervention
Łagowska *et al.*[25]	52 (F)	17·1 18·1	0·9 2·6	Ballet, rowing, synchronised swimming, triathlon; high school	Individual nutrition counselling	9/12 (9× sessions)	Drinks; low-fat/energy foods; supplements; shopping tips; food preparation; dining out; micro and deficiencies	Dietitian	7-d diet record	Post 3, 6, 9 months
Martinelli[24]	7 F (4) M (3)	21·6	2·4	Basketball, American football, shot put, water polo and rugby; elite	Workshop	5/12 (6× sessions)	Fuelling; diet analysis; hydration; recovery; protein; supplements; self-efficacy	Sports nutritionist	3-d diet record	8× prior 8× post
Molina-Lopez *et al.*[27]	14 (M)	22·9	2·7	Handball; national	Activities	8/52 (3× '*ad hoc*' sessions)	Nutrients, nutrition and physical activity, nutritional requirements, Q and A	Nutrition specialist	72-h recall 3-d diet record	3× over 4/12 and weeks 0, 8, 16
Nascimento *et al.*[28]	ADOL M (15), F (6) Adult M (11)	15·4 23·7		Fighting, athletics, cycling, swimming, tennis, beach volleyball, surfing, rowing and sailing; state	Individual nutrition counselling; lecture; online posts	4× 45–60 min, re-evaluations 60 d (6·4–8·5/52)	Hydration; meal frequency; diet quality; food guide; eating tip blog posts	Sports nutritionist	24-h recall	Pre-intervention, post-intervention
Nowacka *et al.*[15]	37 F (8), M (29)	21·5		Canoeing; national	Individual nutrition counselling, group consults	Over a 2-year period, intervention details NR	Nutrition guidelines; nutritional mistakes	Nutritionist	24-h recall	3× d each season (×3) for 2 years

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Table 1. (*Continued*)

	Participants				Intervention				Dietary analysis	
		Age (years)								
Study	*n* (sex)	Mean	SD	Population; calibre	Delivery style	Duration and frequency	Nutrition curriculum	Facilitator	Dietary analysis method	Times administered
Philippou *et al.*[23]	34 F (11), M (23)	15·2	1·5	Swimming; national	Lecture; shopping tours	6/52 (2× half day sessions)	Nutrition issues; Mediterranean diet; dietary supplement use/ misuse	Student dietitian	KIDMED Index	Pre-intervention, post-intervention
Rossi *et al.*[18]	15	19·31	1·0	Baseball; collegiate	Lecture	12/52 (initial 90-min session, then 45-min sessions every 3 weeks)	Energy; macro; micro; hydration; supplements; individual portion sizes; food timing	NR	3-d diet record	Pre-intervention, post-intervention
Valliant *et al.*[26]	11 (F)	19·5	1·0	Volleyball; collegiate	Individual nutrition counselling	4/12 (4× visits)	NR	Dietitian	3-d diet record	Pre-intervention and each month of intervention
Wenzel *et al.*[19]	11 (F)	19·8		Volleyball; collegiate	Individual nutrition counselling	4/12 (3× sessions)	Selecting foods and beverages; personalised needs; practical strategies	Dietitian	3-d diet record	Pre-intervention and each month of intervention
Wittkofski[21]	17 (F)	19	1·3	Volleyball; collegiate	Lecture, handout, activities	3× 30-min during in-season	Food groups; menu ordering; sport nutrition; SCT	Sports dietitian	24-h recall	Pre-intervention, post-intervention
Double-arm studies										
Abood *et al.*[16]	I: 15 (F) C: 15 (F)	19·6	1·1	Soccer, swimming; collegiate	Lecture	8/52 (weekly, 1 h)	Energy; macro; fluid; micro; nutrition principles; nutrition for travel; self-efficacy	NR	3-d diet record	Pre-intervention, 2 weeks post-intervention
Buffington *et al.*[17]	I: 27 (F) C: 20 (F)	22·5		Basketball, swimming, diving, volleyball, soccer, tennis, cheering, cross country, track, fencing; collegiate	Online lecture	12/52 (weekly, 10-min sessions)	CBT in conjunction with energy balance education	NR	24-h recall	Week 1, post-intervention
Chapman *et al.*[20]	I: 37 (F) C: 35 (F)	16		Softball; high school	Lecture, handout	6/52 (weekly, 2× 45-min)	Ergogenic aids; dehydration; pre-competition meal; weight control	NR	24-h recall	Pre-intervention, post-intervention

Table 1. *(Continued)*

	Participants				Intervention				Dietary analysis	
		Age (years)								
Study	*n* (sex)	Mean	SD	Population; calibre	Delivery style	Duration and frequency	Nutrition curriculum	Facilitator	Dietary analysis method	Times administered
Doyle-Lucas *et al.*[13]	I: 146 (M, F) C: 64 (M, F)	15·4	0·2	Ballet; pre-professional	Online lecture	6/52 (3× 30-min)	Female athlete triad; macro; micro; hydration; healthy eating habits; CBT	Dietitian	FFQ	Pre-intervention, post-intervention, 6 week post-intervention
Elias *et al.*[30]	I: 52 (M) C: 53 (M)	Intervention: 18·69 Control: 23·26		Field hockey, football, cricket and rugby; national	Booklets, lecture, group consults	7/52 (7× 60–90 min sessions)	Macro; micro; hydration; nutrition timing; energy balance; supplementation	Sports nutrition background	3-d diet record	Pre-intervention, 1 week post-intervention
Garthe *et al.*[29]	I: 21 (2 F) (19 M) C: 18 (1 F) (17 M)	19·1	2·9	Rowing, kayak, soccer, volleyball, taekwondo, skating and ice hockey; national	Individual nutrition counselling	8–12/52, weekly (average 9·5 weeks)	Basic nutrition; sports physiology; personalised dietary plans/ weight regimen; self-efficacy	Dietitian, exercise physiologist, sports nutritionist	4-d weighed diet record (all) 24-h recall (control)	Pre-intervention, 2× mid + post
Loprinzi[33]	I: 13 (M) C: 11 (M)	15·83	2·69	Wrestling; high school	Lecture, handout	2/52 (3× 25-min sessions)	Food groups; Fe deficiency, food sources; increasing Fe; label reading; how Fe is lost; vitamin supplements	Dietitian	3-d diet record	Pre-intervention, post-intervention
Peitzmeier[31]*	61 (F) I1:17 (F) I2:8 (F) C1:20 (F) C2:16 (F)	NR		Hockey and soccer; collegiate/ national	Lecture, index cards	5/12 I1 – 1 h session, questions, feedback I2 – 5× 20-min sessions, questions, feedback	Hydration; energy content; macros; fast food; the timing of eating (breakfast, pre-exercise, recovery); personalised goals	Dietitian	3-d diet record	Week 1, post-intervention
Rastmanesh *et al.*[11]	I: 42 (NR) C: 30 (NR)	30	7·6	NR; elite athletes with physical disabilities	Lecture, handout	1/12 (4× 3-h)	Food guide pyramid; nutrition and weight loss	Dietitian	3-d diet record	Pre-intervention, post-intervention
Welch *et al.*[32]	I: 10 (F) C: 29 (F)	19·5		Basketball, cross country, field hockey, golf, swimming, softball, volleyball, tennis, track and field; collegiate	Individual nutrition counselling	2–5× sessions	Food groups; dietary guidelines; dietary goals	Dietitian	7-d diet record 24-h recall	Pre-intervention, post-intervention

F, female; NR, not recorded; macro, macronutrients; micro, micronutrients; M, male; ADOL, adolescents; KIDMED Index, Mediterranean Diet Quality Index; SCT, social cognitive theory; I, intervention group; C, control group; CBT, cognitive behavioural theory.

* Peitzmeier[31] assessed two intervention and two control groups.

Table 2. Nutrient intake pre- and post-nutrition education for included single-arm and double-arm studies‡
(Mean values and standard deviations; mean values with their standard errors)

Study	Energy (kcal/d)§		CHO (g/kg per d)		Protein (g/kg per d)		Fat (g/d)		Ca (mg/d)		Fe (mg/d)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Single-arm studies												
Collison *et al.*[14]	1795 ± 48 (−0·2)	1668 ± 595	4·5	4	1·1	0·9	55·8	44·4	876	672	15·9	13·1
Kandiah[12]	N/D	N/D	5·0 ± 0·8	5·3 ± 1·0 (0·0)	1·7 ± 0·3	1·7 ± 0·2 (0·0)	104 ± 14	90 ± 11* (−1·1)	988 ± 76	1001 ± 87 (0·2)	19·2 ± 6·9	19·8 ± 4·3 (0·1)
Łagowska *et al.*[25]; athletes	2354 ± 539	2800 ± 321* (1·0)	5·2 ± 1·3	7·0 ± 1·0* (1·6)	1·3 ± 0·2	1·6 ± 0·2* (1·5)	92·2 ± 7·5	87·4 ± 11·1 (−0·5)	N/D	N/D	N/D	N/D
Łagowska *et al.*[25]; ballet	1640 ± 412	2368 ± 182* (2·3)	4·2 ± 1·1	6·3 ± 0·6* (2·4)	1·1 ± 0·3	1·6 ± 0·2* (2·0)	57·0 ± 18·9	73·2 ± 15·9* (0·9)	N/D	N/D	N/D	N/D
Martinelli[24]	2976 ± 847	2652 ± 740 (−0·4)	5·1 ± 1·4	4·9 ± 1·7 (0·1)	1·7 ± 0·5	1·5 ± 0·4 (−0·4)	99·2 ± 38·2	77·1 ± 23·1 (−0·7)	925 ± 365	1113 ± 826 (0·3)	12·8 ± 2·8	14·5 ± 6·2 (0·4)
Molina-Lopez *et al.*[27]	2975 ± 211	3329 ± 306* (1·3)	4·2 ± 0·4	4·8 ± 0·4* (1·5)	1·5 ± 0·2	1·7 ± 0·3* (0·8)	118·6 ± 22·5	129·6 ± 21·8 (0·5)	1251 ± 338	1235 ± 393 (0·0)	24·2 ± 8·5	24·4 ± 6·1 (0·0)
Nowacka *et al.*[15]; female	1654 ± 426	1807 ± 373* (0·4)	3·8 ± 1·0	4·0 ± 0·7 (0·2)	1·1 ± 0·2	1·2 ± 0·4 (0·3)	52·0 ± 16·5	58·4 ± 16·3 (0·4)	N/D	N/D	N/D	N/D
Nowacka *et al.*[15]; male	2372 ± 379	2762 ± 434* (1·0)	4·4 ± 0·9	5·1 ± 1·0* (0·7)	1·4 ± 0·2	1·5 ± 0·2 (0·5)	78 ± 19·5	91·0 ± 16·9 (0·7)	N/D	N/D	N/D	N/D
Rossi *et al.*[18]	2878 ± 443	3366 ± 451* (1·1)	3·6 ± 0·9	3·8 ± 0·7 (0·2)	1·8 ± 0·3	2·1 ± 0·4* (0·8)	129 ± 21	162 ± 37* (1·1)	N/D	N/D	N/D	N/D
Valliant *et al.*[26]	1756 ± 558	2178 ± 492* (0·8)	3·1 ± 1·1	4·2 ± 1·3* (0·9)	0·9 ± 0·3	1·1 ± 0·3* (0·7)	67·4 ± 27·8	69·0 ± 24·8 (0·1)	N/D	N/D	N/D	N/D
Wenzel *et al.*[19]	56·0 %	70·0 %	3·1	4·1	1·0	1·1	N/D	N/D	N/D	N/D	N/D	N/D
Wittkofski[21]	2524 ± 655	2256 ± 516 (−0·5)	5·4 ± 0·7	4·9 ± 0·9	1·3 ± 0·4	1·0 ± 0·4 (−0·8)	64·5 ± 16·8	65·2 ± 25·1 (0·0)	N/D	N/D	N/D	N/D
Double-arm studies												
Abood *et al.*[16]												
Intervention	1969 ± 414	1974 ± 473 (0·0)	4·2 ± 0·7	4·8 ± 0·8 (0·8)	1·0 ± 0·2	1·2 ± 0·2 (1·0)	52·5 ± 15·3	50·3 ± 13·6 (−0·2)	659 ± 229	309 ± 344 (0·5)	18 ± 12	21 ± 16 (0·2)
Control	2240 ± 366	1947 ± 515 (−0·7; 0·1)	5·5 ± 0·6	4·4 ± 0·7* (−1·7; 0·5)	1·2 ± 0·6	1·2 ± 0·5 (0·0; 0·0)	57·2 ± 14·9	45·4 ± 8·7 (−1·0; 0·4)	918 ± 305	695 ± 329 (−0·7; 0·3)	15 ± 4	13 ± 5 (−0·4; 0·7)
Buffington *et al.*[17]												
Intervention (%E)	N/D	N/D	46·6 ± 15·9	57·0 ± 11·4* (0·8; 0·5)	17·2 ± 7·2	16·5 ± 4·9 (−0·1; −0·7)	33·6 ± 14·0	25·4 ± 8·8 (−0·7; −0·4)	N/D	N/D	N/D	N/D
Control (%E)			47·5 ± 12·6	51·0 ± 12·7	15·6 ± 5·0	19·7 ± 4·8*	34·9 ± 8·6	29·1 ± 10·6 (−0·6)				
Chapman *et al.*[20]												
Intervention (%E)	2054	1892	48·5	51·0	13·0	12·0	39·5	34·0	N/D	N/D	N/D	N/D
Control (%E)	1683	1793	47·0	48·2	9·0	9·5	39·0	41·0				
Doyle-Lucas *et al.*[13]‖												
Intervention	N/D	N/D	N/D	N/D	N/D	N/D	95·2 ± 1·8	88·2 ± 1·6*	N/D	N/D	N/D	N/D
Control							91·7 ± 2·8	89·3 ± 2·5				
Elias *et al.*[30]												
Intervention	2478 ± 364	2879 ± 385*† (1·1; 0·4)	5·3 ± 1·1	5·8 ± 1·2*† (0·4; 1·8)	1·7 ± 0·4	2·1 ± 0·5*† (0·9; 0·7)	75·9 ± 16·2	94·3 ± 19·8*† (1·0; −0·1)	N/D	N/D	N/D	N/D
Control	2801 ± 541	2697 ± 600* (−0·2)	4·4 ± 0·9	4·1 ± 0·6* (−0·4)	1·8 ± 0·4	1·8 ± 0·4 (0·0)	101·7 ± 26·4	96·2 ± 26·8 (−0·2)				

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Table 2. (*Continued*)

Study	Energy (kcal/d)§		CHO (g/kg per d)		Protein (g/kg per d)		Fat (g/d)		Ca (mg/d)		Fe (mg/d)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Garthe *et al.*[29]												
Intervention	3041 ± 578	3585 ± 600*† (0·9; 0·8)	5·4 ± 1·1	6·8 ± 1·3*† (1·2; 1·4)	1·8 ± 0·4	2·4 ± 0·4*† (1·5; 1·8)	99·0 ± 28·3	99·0 ± 21·2† (0·0; −0·5)	N/D	N/D	N/D	N/D
Control	3032 ± 771	2964 ± 884 (−0·1)	5·4 ± 1·7	4·5 ± 1·9 (−0·5)	1·7 ± 0·5	1·7 ± 0·4 (0·0)	104·9 ± 44·8	112·4 ± 30·0 (0·2)				
Loprinzi[33]												
Intervention	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	7·6 ± 2·9	11·3 ± 2·5* (1·4; 0·3)
Control											10·8 ± 3·8*	10·5 ± 3·4 (−0·1)
Peitzmeier[31]												
Intervention 1	2034	2103	4·5	4·6	0·8	1·4	67·5	66·3	797	879	15·9	15·3
Intervention 2	2139	2323	4·9	5·2	1·3	1·4	62·7	71·4	1041	974	17·0	16·6
Control 1	1626	1647	3·4	3·5	1·0	1·1	51·3	48·3	642	688	11·5	13·4
Control 2	1409	1356	3·1	3·2	1·1	0·9	34·7	32·3	646	531	11·7	12·9
Rastmanesh *et al.*[11]												
Intervention	1690 ± 490	1520 ± 450* (−0·4)	N/D	N/D	N/D	N/D	N/D	N/D	715 ± 250	840 ± 300* (0·5)	N/D	N/D
Control¶	1670 ± 430	–							690 ± 270			
Welch *et al.*[32]												
Intervention	1722 ± 1052	1771 ± 852 (0·1; −0·2)	3·5 ± 0·6	4·3 ± 0·8* (1·1; 0·8)	0·7 ± 0·1	0·9 ± 0·3 (0·9; −0·3)	80·4 ± 15·3	57·1 ± 17·7* (−1·4; −0·9)	610 ± 214	822 ± 323 (0·8; 0·2)	6·0 ± 4·1	15·4 ± 13·3 (1·0; 0·4)
Control	1788 ± 654	1893 ± 648 (0·2)	3·6 ± 0·7	3·7 ± 0·8 (0·1)	1·1 ± 0·4	1·0 ± 0·3 (−0·3)	69·5 ± 17·9	73·6 ± 18·9 (0·2)	688 ± 447	731 ± 384 (0·1)	8·9 ± 3·2	12·4 ± 4·9* (0·8)

CHO, carbohydrate; N/D, not defined; %E, percentage energy.
* Significant within-group (pre-post) difference ($P < 0·05$).
† Significant between-group (post-intervention) difference ($P < 0·05$).
‡ Results presented as mean values and standard deviations (within-group effect size; between-group effect size), where available.
§ To convert kcal to kJ, multiply by 4·184.
|| Presented as mean values with their standard errors.
¶ No post-intervention assessment conducted.

reported low baseline energy intakes assessed female athletes, with 1/7 including mixed-sex athletes[15]. In 2/9 studies where authors reported energy intake met the EER at baseline, both reported non-significant decreases which fell below the targeted EER post-intervention (ES −0·4 to −0·5)[21,24].

Carbohydrate intake was assessed in 10/12 single-arm studies. At baseline, mean carbohydrate intake was deemed to be appropriate by the researchers' (>50 % of energy or 6–10 g/kg per day) for the study population assessed in only 2/10 studies[14,21]. In the 8/10 studies where carbohydrate intake was identified to be below requirements at baseline, the range in mean intake (when able to be calculated) was 3·1–5·2 g/kg per d. Post-intervention, this increased to 3·8–7·0 g/kg per d, with 4/8 studies reporting significant increases in carbohydrate intake (ES 0·7–2·4; $P < 0·05$), yet still falling below the researchers' recommendations. In the 2/10 studies deemed to have adequate carbohydrate intake at baseline based on percentage of energy, no significant changes in intake were observed post-intervention[14,21].

Protein intake was reported in 10/12 single-arm studies and was deemed adequate according to author recommendations in 5/10 studies at baseline (1·1–1·7 g/kg per d, when able to be calculated)[15,18]. In the remaining studies identified as having inadequate protein intake at baseline, three also reported protein as inadequate post-intervention (1·1–1·6 g/kg per d), while the other two studies reported small to large increases to meet the targeted protein intake, ranging between 1·2 and 2·1 g/kg per d (ES 0·2–0·8)[15,18]. In the 5/10 studies reporting adequate protein intake at baseline, 4/5 studies maintained an adequate protein intake post-intervention between 0·9 and 1·7 g/kg per d, while one study reported a large reduction post-intervention, falling to the lower limit of the researchers' recommendations (1·0 g/kg per d; ES −0·8)[21].

Dietary fat intake was reported in 9/12 single-arm studies. Of these, 5/9 were reported at baseline to exceed researchers' recommendations (20–30 % of energy), with the remaining four meeting this recommendation at 23–28 % of energy[14,15,21,25]. Post-intervention, 3/5 studies that exceeded baseline recommendations reported non-significant decreases which fell within the recommended 20–30 % of energy[12,24,26], while the remaining two studies still exceeded 30 % of energy post-intervention[18,27].

Fe and Ca were reported in 4/12 single-arm studies, with each of these meeting the researchers' targeted recommendation of >70 % of the RDI/RDA at baseline. Two of these four studies reported non-significant increases for Fe and Ca post-intervention (ES: Fe 0·1–0·4; Ca 0·2–0·3)[12,24]. The remaining 2/4 studies showed no change in Fe intake[14,27], and a decrease in Ca intake to <70 % of the RDI/RDA[14]. However, due to the fair quality of dietary methodology used for micronutrient assessment, these findings are questionable. Other micronutrients reported in 3/4 studies showed mostly adequate intakes at baseline and insignificant changes post-intervention[24,27]. One study examined intake of dietary fibre, vitamin C and dietary cholesterol, with dietary cholesterol showing a significant reduction post-intervention[12].

Change in food group consumption and adherence to the Mediterranean diet were assessed in 3/12 and 1/12 single-arm studies, respectively. One of the studies assessing food group consumption[28] reported athletes (adults and adolescents) as low, adequate or high at baseline and post-intervention based on the Brazilian Food Pyramid Guide. A significant reduction post-intervention in vegetable, fruit and grain intake was reported in athletes classified as adequate at baseline for these food groups ($P < 0·05$), falling below recommended intakes for vegetables. No significant changes were reported for dairy, or meat and egg intake. For athletes classified as low intake for vegetables, fruit and dairy, significant increases were reported for these food groups ($P < 0·05$), achieving the recommended intake for fruits. A significant reduction in meat and egg intake was observed in athletes classified as high intake at baseline ($P < 0·05$); however, these athletes remained above recommended intakes for this food group. No significant change in grain intake was observed in those classified as low at baseline[28]. Another study assessing food groups[21] reported participants met grains, vegetable and fruit groups at baseline, whilst dairy was reported as lower and meat serves higher than recommendations. Non-significant decreases were reported for vegetable, fruit and grain food groups post-intervention. Meat serves decreased to within the recommended intake (2·7 serves), while a large increase in milk intake to within the recommended range was observed post-intervention (2·5 serves; ES 0·9)[21]. The remaining study assessing food groups reported low fruit and grain intake, and high meat, poultry and egg intake, pre-intervention. These food groups remained outside of recommended intakes post-intervention[27]. One study investigated adherence to the Mediterranean diet, reporting a large increase in adherence post-intervention (ES 1·0)[23].

Double-arm studies dietary outcomes

In the double-arm studies (*n* 10), energy intake was assessed in 7/10 studies, where 5/7 used 3–4-d food records, and 2/7 used 24-h recall (one study also used a 7-d food record). Macronutrients were measured in 8/10 studies (7/8 measuring carbohydrate and protein, and 8/8 dietary fat), where 4/8 used 3–4-d food records (one of these also used a 24-h recall), and 4/8 used 24-h recalls (two of these combined this with a 4- or 7-d food dairy). One study measured food groups in addition to dietary fat using an FFQ[13]. Micronutrients were measured in 5/10 studies, using predominantly 3-d food records, with one study using a 7-d food record in addition to the 24 h recall. Identification of nutrition targets was similar to the single-arm studies. Other micronutrients reported in 3/10 studies showed mostly adequate intakes at baseline and insignificant changes post-intervention.

The control groups in the double-arm studies received no placebo or sham intervention and generally only experienced minimal, non-significant within-group changes to dietary intake. There were generally more positive changes in dietary intake within the intervention groups, although not all changes were significant or in the direction targeted. Within- and between-group changes in dietary intake are presented in Table 3. Sufficient information was provided in 6/10 double-arm studies to perform between-group analyses[29,30], with 4/10 failing to provide sufficient data, reducing study quality[11,13,20,31].

Energy intake was compared between-groups in 4/10 studies. Energy intake was significantly increased relative to

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Table 3. Diet quality pre- and post-nutrition education for included single-arm and double-arm studies†
(Mean values and standard deviations; mean values with their standard errors; mean values and 95 % confidence intervals)

	Vegetables (portions/d)		Fruit (portions/d)		Grains (portions/d)		Dairy products (portions/d)		Meat, poultry and eggs (portions/d)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Single-arm studies										
Molina-Lopez *et al.*[27]‡	2·2	2·1	1·7	1·1	3·6	3·4	2·7	2·7	4·5	6·8
	1·7, 2·8	1·6, 2·6	0·7, 2·7	0·7, 1·6	2·8, 4·4	2·9, 3·9	1·8, 3·6	2·2, 3·3	6·3, 8·6	5·8, 7·8
Nascimento *et al.*[28]‡§ (adequate)	6·3	2·5*	6·6	4·8*	9·8	6·1*	5·0	3·3	2·1	2·8
	2·5, 16·0	1·4, 4·8	5·0, 8·7	2·6, 8·6	6·7, 14·0	3·5, 10·0	3·8, 6·8	1·4, 8·0	1·6, 3·0	1·8, 4·0
Nascimento *et al.*[28]‡§ (low)	1·6	2·2*	2·4	4·6*	3·0	3·8	1·8	2·5*	4·0	2·8*
	1·6, 3·1	0·8, 7·8	1·2, 5·0	1·6, 12·0	1·7, 5·5	2·1, 6·8	1·1, 2·9	1·7, 3·7	3·0, 5·0	1·7, 4·0
Wittkofski[21]	3·1 ± 2·3	2·8 ± 2·8 (−0·1)	2·5 ± 2·7	1·4 ± 1·5 (−0·5)	9·6 ± 6·0	7·6 ± 2·6 (−0·4)	4·1 ± 1·8	2·7 ± 1·5 (−0·8)	1·3 ± 1·1	2·5 ± 1·5 (0·9)

	Pre	Post
Adherence to Mediterranean diet (KIDMED score)‖		
Philippou *et al.*[23]	5·7 ± 2·1	7·6 ± 1·7 (1·0)

	Fruit and vegetables (portions/d)		Grains (portions/d)		Dairy products (portions/d)		Meat, poultry and eggs (portions/d)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Double-arm studies								
Doyle-Lucas *et al.*[13]¶			N/D	N/D			N/D	N/D
Intervention	4·9 ± 0·1	4·5 ± 0·1*			2·5 ± 0·1	2·7 ± 0·1		
Control	4·9 ± 0·2	4·4 ± 0·2			2·5 ± 0·2	2·4 ± 0·2		

N/D, not defined.
* Significant within-group (pre-post) difference ($P < 0.05$).
† Results presented as mean values and standard deviations (within-group effect size; between-group effect size), where available.
‡ Presented as mean values and 95 % confidence intervals.
§ Nascimento *et al.*[28] classified participants as adequate or low based on meeting recommended food portion number (or adequate and high for meat and eggs).
‖ Adherence to the Mediterranean diet is described as poor (score: 0–3), medium (score: 4–7) or good (score: 8–12).
¶ Presented as mean values with their standard errors.

control in two studies (ES 0·4–0·8; $P < 0.05$)[29,30], while trivial, non-significant between-group differences in energy intake were observed post-intervention in two studies (ES −0·2 to 0·1; $P > 0.05$)[16,32].

Moderate to large increases in carbohydrate intake relative to control were reported in three (ES 0·5–0·8; $P > 0.05$)[16,17,32], and a significant, large increase reported in two studies (ES 1·4–1·8; $P < 0.05$)[29,30]. Similar variability was reported across studies with protein intake post-intervention. Two studies reported increases in intake relative to control (ES 0·7–1·8)[29,30]; two others reported small to moderate reductions relative to control (ES −0·3 to −0·7)[17,32]. One study reported no between-group difference (ES 0·0)[16]. A moderate increase in fat intake relative to control was reported in one study (ES 0·4)[16], while trivial to large reductions relative to control were found in four studies (ES −0·1 to −0·9)[17,29,30,32]). Between-group differences in Ca intake were reported in 2/10 studies[16,32], with small increases reported in both studies (ES 0·2–0·3). Small to moderate increases in Fe intake compared with control were reported in three studies (ES 0·3–0·7)[16,32,33].

The remaining four double-arm studies did not conduct between-group analyses or did not provide sufficient information for ES to be calculated, contributing to the poor study quality and difficulty in drawing firm conclusions. Within-group analysis was performed in one of these studies, indicating a moderate reduction in energy intake (ES −0·4), and a moderate increase in Ca intake (ES 0·5), post-intervention[11].

Discussion

This is the first systematic review to evaluate the effectiveness of nutrition education programmes on the dietary intake of athletes. Overall, the impact of nutrition education programmes was varied. Given the range of intervention modalities and durations, the limitations in the dietary assessment methodologies employed and the small number of studies conducting intervention-control comparison analyses, it is difficult to make firm conclusions as to the efficacy of the interventions or which interventions were best. Study quality was rated poor to fair-range, also indicating room for methodological improvement. Despite the significant investment in nutrition education of athletes, there is limited and generally low-quality evidence of the efficacy of interventions. Well-designed and rigorous research application is needed in this area to inform future best practice.

Of the twenty-two studies, more than half (*n* 12) had a single-arm design which assessed dietary intake pre- and post-intervention (Table 1). While there was some evidence of intervention benefit, many of the ES were trivial or small and not statistically significant (Tables 2 and 3). Carbohydrate intake in particular often failed to meet the researchers' set targets, although with the age of the studies, many of these recommendations were outdated and likely inappropriate for the sports assessed[9]. Remarkably, intervention time was only able to be calculated for 3/12 studies and ranged from 180–300 min (3–5 h), across a 2- to 39-week duration.

In the double-arm studies (Table 1), none of the control arms used an alternative or 'sham' intervention to manage differences in group attention. Control groups generally experienced minimal changes; however, a limitation present in several studies was the failure to perform analysis between intervention and control groups (4/10 studies). Analysis was primarily conducted within-groups and rendered the use of the control group to qualitative comparison only. Across the double-arm studies, only 2/10 reported consistent, significant dietary improvements with ES in the large range[29,30]. The remaining double-arm studies demonstrated inconsistent dietary outcomes, with calculated ES varying in both direction and magnitude. Aligning with the single-arm study results, carbohydrate intake often failed to reach the researchers' targeted levels, although these may have been too high for the sports assessed[9]. In several instances, the control group outperformed the intervention group with respect to increasing nutrient intake. Most (9/10) double-arm studies provided sufficient detail on the intervention time which ranged from 60 to 720 min (1–12 h) over 2–12 weeks.

Across all studies, most of the interventions focused on face-to-face group education, with some studies using resources such as handouts or emails to participants, and others using individual consults and meal plans. Most of the facilitators appeared to have training in nutrition/dietetics, although facilitator background/qualifications were not always provided. The heterogeneity of these factors in addition to the range in approaches used to assess dietary outcomes makes it impossible to discern the overall effectiveness of interventions, nor which interventions are superior for improving dietary intake in athletes.

Given the heterogeneity and limited quality of the included studies in this review, few conclusions can be drawn as to the effect of nutrition education on dietary practices of athletes. A summary table in the form of a checklist has been constructed by authors to aid discussion of relative strengths and limitations of included studies (Table 4). This aims to succinctly critique the common flaws observed, while also guiding future nutrition education research. The checklist, Dietary Intake and Nutrition Education Reporting for Sports, outlines factors which would inform stronger study design, methodology and reporting. Appraisal of the literature included in this review identified four areas common to nutrition education intervention studies which require attention: participant characteristics, targeted dietary outcomes of the intervention (and underpinning rationale), intervention characteristics and dietary methodology. These areas are described below, and in further detail in online Supplementary Table S3.

Participant characteristics

Adequate participant description is necessary as different interventions may be more efficacious at different age stages or levels of athletic calibre. While most studies in this review reported age and variance (17/22), sex (21/22), sport (21/22) and athletic calibre (22/22), only two studies adequately described training characteristics (inclusive of frequency, intensity, duration and type)[9]. Detailed training information is necessary to evaluate athlete energy and nutrient requirements[9]. Moreover, to make sense of current nutrition guidelines, body weight and composition is important, especially how these may change over the intervention period. Only ten and thirteen studies reported on body composition and body weight, respectively. Detailed protocols and error (e.g. technical error of measurement) associated with the assessment of body composition are also an important inclusion in the methods of the paper. Only four papers in this review provided such information[9].

Targeted dietary outcomes of the intervention

Defining intervention targets and desired dietary outcomes is essential for assessing intervention impact. Energy, macronutrient and micronutrient targets were defined and justified by only three[9], two[9] and one[9] studies, respectively. Given athlete dietary goals can vary over a season or even a training period, the goals of the athletes may warrant lower or higher intake of energy, macronutrients or micronutrients, which needs to be explained with a clear underpinning rationale provided[34].

Intervention characteristics

Intervention characteristics should be transparent. Details on the curriculum covered (17/22), the facilitator background and experience (12/22), modality of intervention used (individual or group, in-person or virtual) (19/22), as well as session duration, frequency and the total number of sessions (7/22) were not covered comprehensively across studies[34]. The total amount of intervention minutes/hours should be provided. Participant attendance and compliance are also important and only half (11/22) of the studies examined these parameters. Underpinning behavioural theory and techniques are critical[35]. Clearly, there is a robust body of research outlining how behavioural support is needed to facilitate dietary change, yet many of the studies did not describe use of these methods. Process evaluation including how the participants perceived the intervention is important for determining how well the intervention was received, and this was only examined in two studies. Lastly, sustained dietary change is also relevant when evaluating intervention efficacy, and only three of the included studies assessed this[36,37]. Clearly, financial or resource limitations may make follow-up after the intervention challenging.

Dietary methodology

A number of the included studies did not appropriately apply dietary methodology to their population, for example, 3–4-d food diaries are insufficient to examine intakes of micronutrients[38]. In this case, combining methods such as using a FFQ for micronutrients with a food diary, which is better for quantifying energy and macronutrients, is recommended[36,37], although the level of agreement of FFQ is limited at the individual rather than group level[39]. The plausibility of data is also important, and potential under-reporting should be assessed[22]. This requires capture of

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Table 4. Study design, methodology and reporting summary checklist of included studies (*n* 22), Dietary Intake and Nutrition Education Reporting for Sports (DINERS) checklist

Item	Yes	No	Unable to determine/not applicable
Participant characteristics			
Age	17	5	0
Sex	21	1	0
Athletic calibre	22	0	0
Sport type	21	1	0
Representative sample recruited	6	15	1
Training characteristics (type, frequency, intensity and duration)	2	20	0
Body composition assessed at baseline	10	12	0
Body composition assessed at post-intervention	10	12	0
Body composition assessment protocols clearly defined	4	5	0
Weight change assessed pre- and post-diet	13	9	0
Targeted dietary outcomes			
Energy intake targets defined and justified	3	17	2
Macronutrient targets defined and justified	2	18	2
Micronutrient targets defined and justified	1	16	5
Fluid or other dietary outcomes justified and defined	0	15	7
Dietary outcomes linked to athlete goals	3	18	1
Intervention characteristics			
Curriculum covered is clearly described	17	5	0
Instructor background/qualifications described	12	10	0
Modality (electronic, face to face, individual and group) described	19	2	0
Session characteristics (individual session duration, number and frequency) described	8	14	0
Duration of the intervention	18	4	0
Compliance/attendance	11	10	1
Behavioural Theory clearly defined and justified	5	16	1
Previous dietary education outlined	6	16	0
Process evaluation by participants	2	20	0
Follow-up or retention outlined if applicable	3	10	9
Dietary methodology			
Method used to assess nutrients is appropriate (e.g. food diary, FFQ)	10	12	0
Dietary collection methods well described	20	2	0
Participant *n* adequate for dietary methods used	20	2	0
Number of collection days and description clearly defined	22	0	0
Number of days collected for primary nutrient justified	12	8	0
Participant instruction clearly described	9	11	2
Checking and cleaning of diet data well described	11	8	2
Dietary analysis software well described and appropriate	17	3	2
Background/qualifications of researcher conducting diet analysis is appropriate	5	14	3
Energy expenditure empirically measured or prediction provided	7	15	0
PAL level/under-reporting assessed	0	22	0
Revised nutrient requirements addressed – Fe altitude, amenorrhoea	1	21	0
Energy reported as kJ/kg	3	17	2
Carbohydrate expressed as g/kg per d	6	14	2
Protein expressed as g/kg per d	7	13	2
Fat (% of energy reported)	13	7	2
Fat types reported when relevant	2	7	13
EAR/RDA and relevant sports guidelines used for micronutrients	5	13	4
Proportion of participants meeting or under recommendations reported	3	18	1
Contribution of diet supplements/sports foods to intake well described	2	20	0

PAL, physical activity level; EAR, Estimated Average Requirement.

training loads; technology such as accelerometers, heart rate monitors or Global Positioning System trackers may be helpful as doubly-labelled water is unlikely to be available or affordable in most situations[22]. Another major flaw in included papers was the reporting of mean intakes of energy and macronutrients which may be skewed by athletes with extremely high or low intakes[40]. While mean intake can be useful, it is stronger to report the proportion of participants who reach the dietary targets as this facilitates a better assessment of intervention effectiveness in the cohort[40]. Similarly, in the case of micronutrients, it would be useful to not only check the proportion of participants meeting the Estimated Average Requirement and RDI/RDA for their age and sex but also report the proportion of participants meeting other sports nutrition specific targets which may be higher than those for the general population[9]. How the nutrient intake from dietary supplements contributes to intakes should also be detailed, and only two studies in this review reported on this[9]. Finally, the rigour of data capture and the background/experience of the researcher conducting the dietary analysis (reported in 5/22 studies) is also relevant to the quality of the dietary outcomes. Use of self-report apps may make data capture easier but not necessarily accurate[41].

Although the major limitation of this review is the quality of the literature that informs it, a major strength is the detailed synthesis of the studies and the construction of the Dietary Intake and Nutrition Education Reporting for Sports checklist table (Table 4) which succinctly summarises the strengths and limitations of the included studies while also guiding future research practice. Nonetheless, the authors acknowledge some limitations of this review including studies excluded if published in languages other than English which poses a risk of publication bias. Further, no meta-analysis was performed due to the heterogeneity of included studies.

In conclusion, there is limited research informing the efficacy of nutrition education interventions in athletes, and what is available is of poor to fair quality, reporting varied outcomes. The findings of the review highlight (1) the requirement for ongoing nutrition education of athletes as they commonly report energy and carbohydrate intakes below recommendations, and (2) the importance of carefully planning interventions to ensure meaningful outcomes is aligned with sport-specific nutritional requirements that can be clearly interpreted and subsequently reported by sports nutrition professionals and researchers. As nutrition education is a key strategy to enhance dietary intake in athletes and there is substantial investment in nutrition education interventions across the broader sporting context, there is a need for rigorous research in this area to inform best practice.

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Supplementary material

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