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Systematic Review & Meta-Analysis

Qualities of Effective Nutrition Education Interventions in Athletes: A Systematic Review and Meta-Analysis

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Abstract

International Journal of Exercise Science 19(2): 2015, 2026. Nutrition knowledge (NK) is consistently reported as low among athletes, potentially limiting optimal dietary intake, performance, recovery, and overall health outcomes. Sports dietitians have a responsibility to provide effective nutrition education and increase NK in athletes. Nutrition education interventions have been shown to improve NK, but practical application standards for designing and conducting nutrition interventions in athletes has yet to be established. The purpose of this meta-analysis is to measure the overall effect of nutrition education interventions on NK in athletes and identify characteristics of nutrition education interventions that effectively increase NK. Seven databases (Academic Search Premier, SPORTDiscus, MEDLINE, ERIC, Health Source: Nursing/Academic Edition, CINAHL Plus with Full Text, and Consumer Health Complete) were searched, yielding 125 studies. Fourteen studies met inclusion criteria and represented 755 athletes (ages 10-32) from various sports. SPSS was utilized to perform the meta-analysis with a random-effects model and DerSimonian-Laird procedure, and effect size (ES) estimates were expressed as Hedges' *g*. The overall ES of nutrition education intervention on NK was .949 ($p < .001$, 95% CI [.728, 1.171]), indicating a large statistically significant positive effect. Moderator analyses indicated that study design ($Q = 12.577$, $p < .001$), mode of intervention ($Q = 17.479$, $p < .001$), length ($Q = 12.029$, $p = .002$), and use of validated NK survey ($Q = 19.430$, $p < .001$) significantly influenced variation in ES. No significant differences were found for intervention type and participant age. Funnel plot asymmetry suggests potential publication bias, although Egger's test was non-significant ($p = .897$). Findings support the overall effectiveness of nutrition education interventions and provide practical insight into factors that may contribute to their success.

Keywords: Sports nutrition, registered dietitian, adolescent athlete, performance outcomes

Introduction

Nutrition knowledge (NK) is defined as the individual cognitive process related to information on food and nutrition,[1] and is the primary step in making healthful dietary choices and may promote healthy eating habits. Athletes specifically have increased nutrition needs due to

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increased energy expenditure and physiological adaptations that occur from consistent training for sport.[2] Research emphasizes the importance of adequate nutrition for athletes, because insufficiency can lead to poor performance and multiple negative long-term health outcomes such as low energy availability, low bone mineral density, and frequent illness or injuries.[3,4] Unfortunately, research suggests athletes have low levels of nutrition knowledge[5,6]; however, it can be improved through nutrition education interventions.[7]

Multiple studies have conducted education interventions to increase NK in athletes, and interventions included in this review highlight in-person lectures or individual counseling, group discussions or team building workshops, grocery shopping activities, cooking demonstrations, remotely delivered programs, online videos and mixed media, articles or self-directed learning, text-messages, and personalized feedback from dietary logs. The involvement of a nutrition professional is also a recommended approach to improve the validity and accuracy of information provided.[7,8] Registered dietitians (RDs) are often referred to because they are food and nutrition experts, and some specialize in working with active populations and are known as sports or performance RDs. The primary role of a sports dietitian is to disseminate scientific literature and provide accurate and practical nutrition recommendations for athletes to implement into their lifestyle and training.[9] Daily tasks may range from individual athlete nutrition counseling, group or team educations, supplement evaluations, game day nutrition logistics and fueling strategies, and cooking demonstrations to name a few. Nutrition education interventions are essential for bridging the gap of knowledge between the athlete and the desired nutrition outcome.

To our knowledge, there is not a current synthesis of literature identifying specific characteristics of successful nutrition education interventions with athletes. Filling this gap and clarifying the qualities that make these interventions successful is necessary to provide recommendations for future research and further make evidence-based literature more practical for sports dietitian to apply to their work with athletes. This meta-analysis measures the overall effect of nutrition education interventions on athlete NK and more specifically identifies significant moderating variables that contribute to the intervention's effectiveness. The goal is to identify and summarize intervention characteristics that are effective at improving NK among athletes. This information will help provide suggestions for future research utilizing nutrition education interventions, as well as registered dietitians and other nutrition professionals designing and implementing evidence-based nutrition education interventions in their practice with athletes.

Methods

Sources and Search Strategy

This meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Figure 1). The principal investigator utilized the aggregator platform EBSCOhost to access the databases on May 10, 2024. Databases included Academic Search Premier, SPORTDiscus, MEDLINE, ERIC, Health Source: Nursing/Academic Edition, CINAHL Plus with Full Text, and Consumer Health Complete. The "Other" source utilized was OneSearch provided by the University of Mississippi online library. Search terms included: "education," "intervention," "sports nutrition knowledge," "nutrition knowledge," "(athlet* or sport)," and "pre and post OR before and after." All terms were used in combination with one another. Some articles did not report a standard deviation (SD), standard error (SE), or pre–post correlation coefficient (r), making them unusable for calculating effect sizes, standard errors, and study weights. When the pre–post correlation was reported, it was used directly in the variance estimation for standardized mean gain calculations. If a pre–post correlation was not provided, but the study cited a previously validated instrument with an available reliability coefficient, the reported reliability statistic was used as an approximation of the pre–post correlation, consistent with recommended meta-analytic procedures for pre–post designs.[10] This study is a meta-analysis of previously published research and does not involve direct interaction with human subjects or access to identifiable private information; therefore, Institutional Review Board (IRB) approval was not required, but the procedures of research meet the ethical standards of the *International Journal of Exercise Science*.[11]

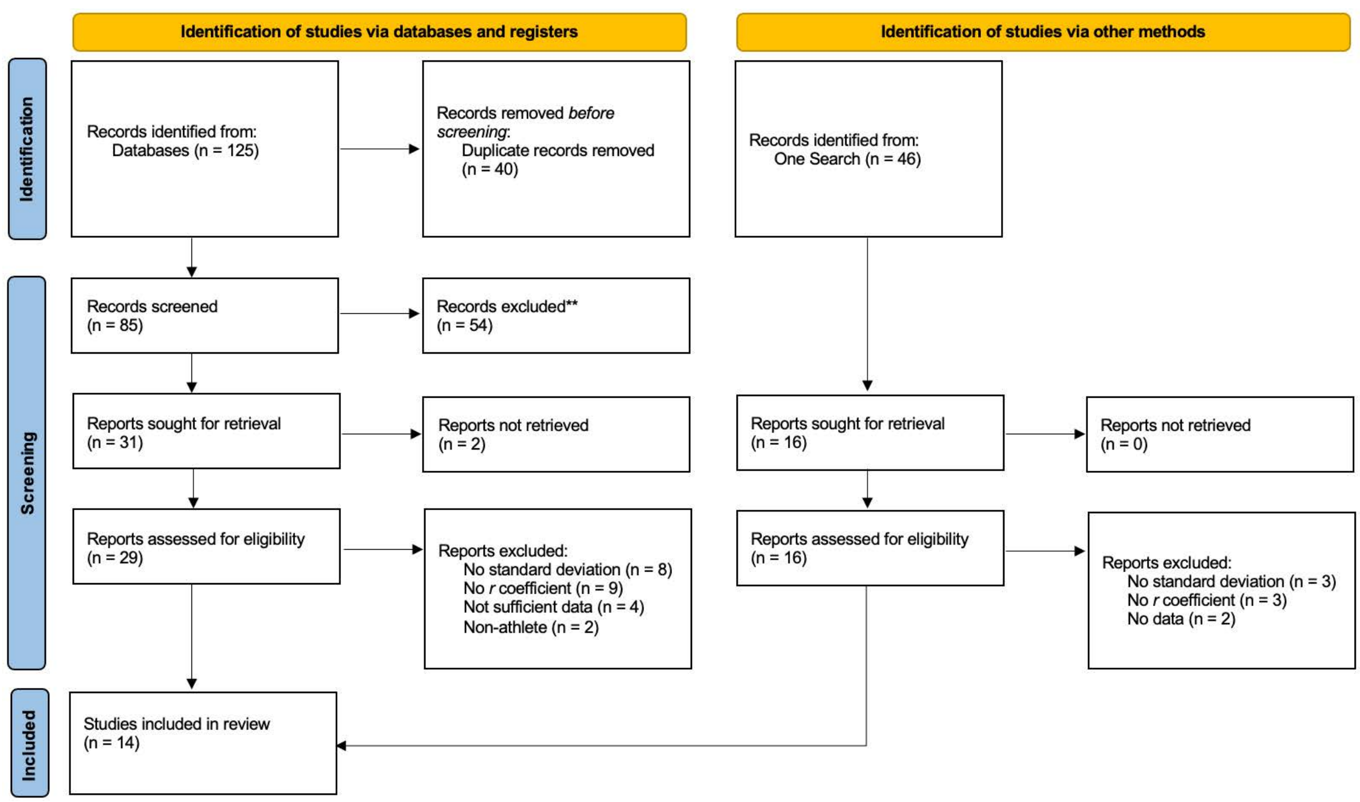

Figure 1. Prisma Flow Diagram.

Study Selection

Following the PICOS framework, the population, intervention, comparison, outcome, and study design are described with inclusion and exclusion criteria in Table 1. This meta-analysis was conducted in athlete and athletic populations that were classified as such in the primary research articles. The primary investigator independently screened each study, and the second reviewer confirmed eligibility, and any discrepancies were solved by the consensus of the research team and data extraction was performed independently of software tools. This meta-analysis protocol was not prospectively registered with PROSPERO prior to the initiation of the study.

Table 1. PICOS Criteria for Inclusion and Exclusion.

Parameter	Inclusion Criteria	Exclusion Criteria
Population	· Athletes of all types (recreational, elite, professional, tactical) · Active individuals · Any age	· Non-active population · Coaches
Intervention	· All forms of interventions (individual, group, online, counseling, lecture, posters, etc.)	· Studies without intervention between pre- and post-NK surveys
Comparison	· Pre- and post-nutrition knowledge scores · Reported survey reliability (e.g., r, Cronbach's alpha)	· Single time NK assessment · Surveys without test-retest reliability or citation of original reliability
Outcomes	· Nutrition knowledge (general, sports, total) · Standardized mean differences · SD	· Studies not reporting NK outcome measure · Studies without mean differences and SD
Study Design	· All study designs · Written in English	· Studies not reporting pre- and post-measures · Not written in English

Sample Characteristics

The final sample included 755 athletes ages 10 to 32 years old, with many athletes (73%) in high school or younger. Athletes ranged from participating in soccer, football, hockey, combat sports, and triathlons. Further characteristics such as author, year, specific athlete type, type of intervention, design, and length of the 14 studies are presented in Table 2. There were seven studies designated as double-arm design for this analysis, but only if the control group did not receive an intervention and still participated in pre- and post-survey assessments. Some studies contained two separate intervention groups, in which both groups received education interventions, and were classified as single-arm studies for the purpose of calculating the ES for each intervention group (n = 11). For example, Nascimento and colleagues compared adults and adolescents who both received nutrition education; therefore each group was analyzed as a single-arm in this analysis.[12] One study with two intervention groups compared classroom and online learning and was run as two single-arm analyses.[13] Another study analyzed retention of NK multiple times after the end of the intervention, in which the immediate post-survey scores were utilized for this analysis.[14] Overall, 14 articles were included in this meta-analysis, with individual characteristics organized in Table 2.[5,8,15–23]

Table 2. Individual Article Characteristics.

Author (Year)	*n*	Athlete Type	Ages	Intervention Details	RCT	Length
Patton-Lopez MM et al. (2018)[15]	217 males and females	High-school soccer players	14–19 years	WAVE obesity-prevention program: age-specific health assessments, face-to-face sports-nutrition lessons, experiential learning, and team-building workshops.	N	2 yrs
Gao Z et al. (2022)[13]	41 males	Youth soccer players	15 years	Quasi experimental: one group received traditional classroom nutrition teaching; the other group learned via curated articles on a WeChat official account.	N	12 weeks

Simpson A et al. (2017)[16]	17 males	Elite field hockey players	18–20 years (19 ± 0.7)	MealLogger app intervention: participants logged meal images 3×/week and received individualized dietitian feedback; weekly nutrition fact sheets and short (1–3 min) topic videos delivered via app; access to materials was optional to support self-directed learning.	N	6 weeks
Larose D et al. (2022)[14]	23 males	University football athletes	22 ± 1 years	Combined intervention: sports-nutrition lectures with hands-on cooking workshops targeting nutrition knowledge, intention, perceived behavioral control, dietary intake, and diet quality.	Y	3 weeks
Debnath M et al. (2023)[5]	105 males	Football (n=26); ice hockey (n=27); athletics (n=26); swimming (n=26)	14–18 years	Face-to-face nutrition counseling twice weekly (60 min/session) based on baseline dietary/ training/anthropometric assessment; included workshops, lectures, demos, quizzes, and hands-on activities; diet goals set and personalized feedback provided to optimize diet quality and reduce bias.	Y	8 weeks
Valliant MW et al. (2012)[17]	11 females	Division I volleyball	19–22 years	Individualized nutrition intervention based on each participant's NDSR dietary analysis. An RD met one week after food-diary submission for four total face-to-face visits throughout the season.	N	16 weeks
Rossi FE et al. (2017)[18]	30 males	Division I baseball	Intervention: 19.3 ± 1.0 years; Control: 19.8 ± 1.4 years	An initial 90-minute session led by the investigator with slideshow and guided discussion on baseball-specific nutrition. Reinforcement sessions (45 min) were held every three weeks with groups of five at the university dining hall.	Y (control group did not complete follow-up survey)	12 weeks
Heikkilä M et al. (2019)[19]	62 males and females	Endurance athletes	18 ± 1.4 years	Three 90-minute nutrition-education sessions with lectures, discussions, exercises, and individual and group work taught by nutritionist. Second group also attended education sessions in addition to access to MealLogger app with nutritionist feedback.	Y	5 weeks
Young H et al. (2023)[20]	40 males and females	University athletes	Freshman through doctoral level; exact age not reported	Three nutrition-education text messages sent per week (reviewed by RD's).	N	4 weeks

Abood DA et al. (2004)[21]	30 females	University soccer & swim	Intervention: 19.6±1.1 years; Control: 19.4±1.2 years	Eight 1-hour weekly group sessions incorporating Social Cognitive Theory.	Y	10 weeks
Nascimento M et al. (2016)[12]	32 males and females	Combat/fighting sports: boxing, taekwondo, karate, judo, jiu-jitsu, capoeira, wrestling (n=16), athletics (n = 3), cycling (n = 1), swimming (n = 6), tennis (n = 2), beach volleyball (n = 1), surfing (n = 1), rowing (n = 1), sailing (n = 1)	Adolescents: 12-19 years Adults: 20-32 years	One face-to-face lecture + four 60-minute individual nutrition-counseling sessions.	N	34 weeks
Reading KJ et al. (1999)[22]	33 males	Competitive male hockey players (adolescent and young adult)	10–21 years	Four modules delivered in two separate 1-hour sessions (one week apart), including lectures, large-group discussions, video presentations, grocery-shopping activity, and individual tasks.	N	2 weeks
Tektunalı Akman C et al. (2024)[8]	83 females	Adolescent elite athletes from three clubs (football n = 34; basketball n = 16; volleyball n = 33)	15–18 years	Six face-to-face nutrition-education lectures with an RD.	Y	6 weeks
Tan X et al. (2022)[23]	14 males and females	Junior elite triathletes	18.9 ± 1.6 years	Weeks 1-5: remotely delivered program: 5-week nutrition education series on Microsoft Teams with visual aids, online chat, quizzes, etc. Weeks 6-8: 30-minute individual consultations with a sports RD	N	8 weeks

Note: Randomized Control Trial (RCT); Yes (Y); No (N); Nutrition Data System for Research (NDSR); Registered Dietitian (RD); Obesity Prevention in Active Youth (WAVE).

Statistical Analysis

After final articles were selected, original data such as standardized mean gain between pre- and post-assessments of NK, SD, and reliability coefficient (r) were extracted. These values were used to calculate the effect size (ES), standard error (SE), and study weights. For double-arm studies, ES was calculated using the Campbell Collaboration's online effect size calculator. Because the Campbell calculator does not support single-arm (pre–post) study designs, standardized mean gain effect sizes for single-arm studies were calculated in Excel following recommended procedures for pre–post designs.[10] Specifically, the standardized mean gain was computed as the mean difference divided by the pooled standard deviation, and variance estimation incorporated the pre–post correlation. When the pre–post correlation was not reported, the reliability coefficient of the instrument was used as an approximation. All ES estimates were expressed as Hedges' g.

Assessment of Publication Bias & Quality of Evidence

Publication bias was assessed using multiple complementary approaches. Funnel plots were visually inspected for asymmetry to evaluate potential small-study effects. Egger's regression intercept test was conducted, with statistical significance set at $p < .05$ to indicate potential publication bias. In addition, the trim-and-fill method was applied to estimate the number of potentially missing studies and to examine the impact of such studies on the pooled effect size. Consistency across these methods was considered when determining the likelihood and magnitude of publication bias.

Further, the Downs and Black 22 checklist was utilized by two researchers to assess the risk of bias and methodological quality of individual studies.[24] Two evaluators independently completed the quality assessment for each included study. Any discrepancies in scoring were discussed and resolved through consensus to ensure consistency and methodological rigor. Final quality scores were determined collaboratively

Overall Certainty of Evidence

The grading of recommendation, assessment, development and evaluation (GRADE) approach was used to evaluate the overall certainty of evidence across studies (Table 7). This approach provides a summary rating for the body of evidence related to the primary outcome (nutrition knowledge), rather than rating each individual study. A "high" quality rating indicates that researchers can be very confident in the estimate of effect; "moderate" indicates researchers can be reasonably confident; "low" or "very low" indicates researchers have limited confidence (i.e. the true effect may be substantially different from the estimation of the effect) or that researchers have little confidence in the estimate, respectively. As supplied in the Cochrane resources, the GRADE assessments were determined based on the following criteria: study design (i.e. randomized control trial [RCT] or non-RCT), limitations or risk of bias, inconsistency, indirectness, imprecision, and other considerations such as magnitude of effect and dose response.[25] Two researchers independently conducted the GRADE evaluation and reconciled differences to finalize the overall certainty rating for the evidence base.

Results

Overall ES

From the 14 studies, a total of 20 ES were calculated. This occurred because several studies contained multiple independent intervention arms or reported separate pre-post comparisons that met the inclusion criteria; therefore, each eligible comparison was treated as an independent effect size in the analysis. Results found the effect of nutrition education intervention on NK to have a standardized mean difference ES of .949 with SE = .113, $z = 8.394$, 95% CI [.728, 1.171] (Table 3). This indicates that, on average, nutrition education interventions increased nutrition knowledge by nearly one standard deviation, which reflects a practically meaningful improvement in applied sports nutrition contexts. The z-value for testing the null hypothesis is 8.394, $p < .001$, indicating the mean ES is not equal to zero and there is a significant effect of nutrition education intervention on NK. The forest plot for overall ES is seen in Figure 2. Variation in the overall ES was checked with a homogeneity of ES test (Q = 112.469, df = 19, $p < .001$). This tells us that the true ES is not the same across all studies and the variation may not be due to sampling error alone. Overall heterogeneity measures outputted $T^2 = .163$ and $I^2 = 83\%$. ES estimates measured 95% PI [.068, 1.831], which indicates the true ES may be as low as .068 in some populations and as high as 1.831 in others.

A sensitivity analysis was conducted to evaluate the influence of statistical outliers. Studies with extremely large, standardized effect sizes (Hedges' $g > 5$) were identified through visual inspection of the forest plot and influence diagnostics. One study exceeded this threshold and exerted a disproportionate impact on the pooled estimate; therefore, it was removed in the sensitivity analysis. As shown in the forest plot, the study by Abood and colleagues[21] reported an ES of 5.34 and was removed. After removing this outlier, the pooled ES decreased slightly to .891 with SE = .106, z = 8.380, 95% CI [.638, 1.100]. This adjustment resulted in minor changes to the heterogeneity measures: T^2 = .138, I^2 = 81%, and 95% PI [.078, 1.704]. Overall, these minor effects reflect robust results and further contribute to credibility.

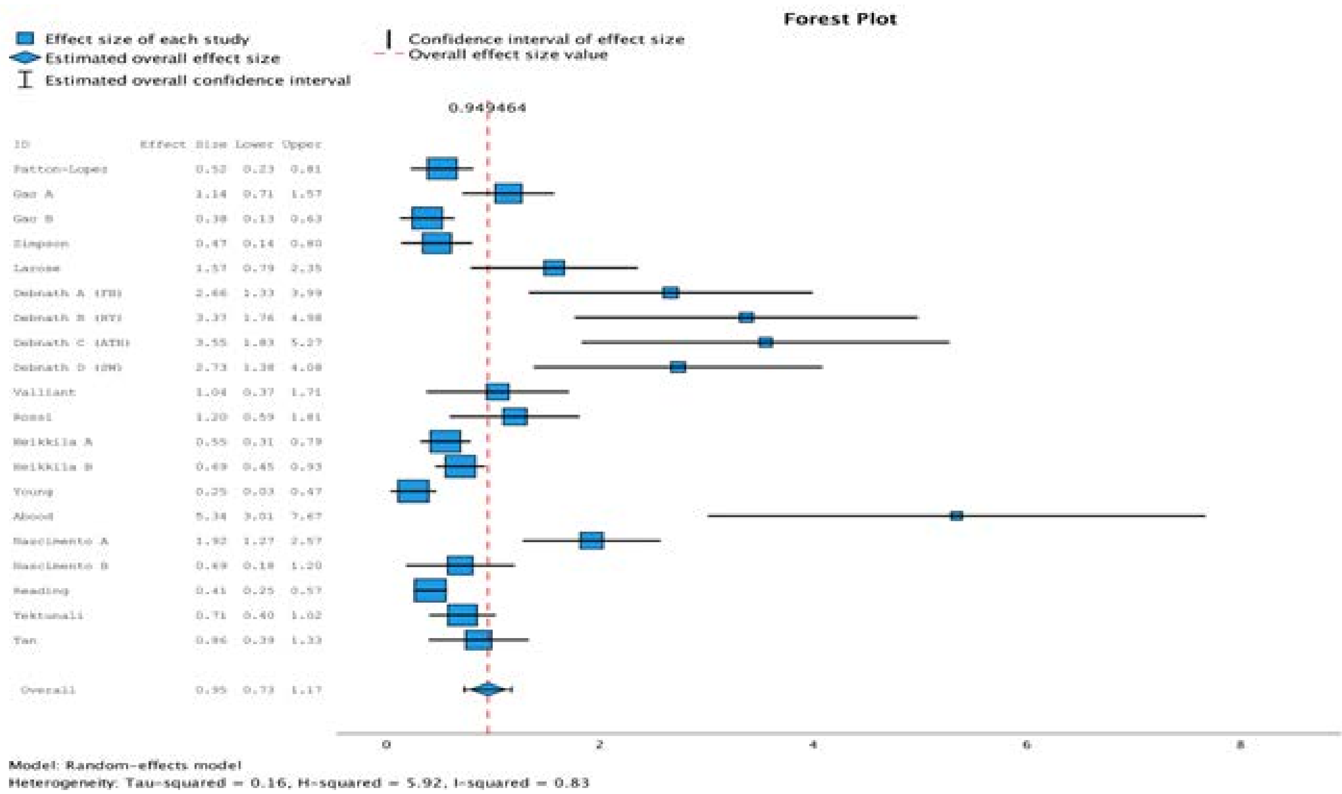

Figure 2. Overall ES.

Table 3. Overall ES for Nutrition Intervention on Nutrition Knowledge.

	ES	SD	Z	*p*-value (2-tailed)	95% CI		95% PI	
Overall ES	.949	.113	8.394	.000*	.728	1.171	.068	1.831

*$p < .001$; ES = Effect Size; CI = Confidence Interval; PI = Prediction Interval

Moderator Analyses

ES for each moderating variable is presented in Table 4. The type of study design had an overall significant moderating relationship between nutrition intervention and NK (Q = 12.577, $p < .001$). Double-arm studies utilizing a control group demonstrated a large mean ES of 2.107, 95% CI [1.353, 2.861], whereas single-arm studies without a control group showed a smaller but still statistically significant ES of .699, 95% CI [.508, .891]. Although both subgroup effects were positive, the substantially larger ES observed in double-arm studies may reflect not only greater intervention effectiveness but also methodological influences such as improved internal validity or reduced risk of overestimation in controlled designs.

Mode of intervention also significantly moderated outcomes (Q = 17.479, $p < .001$). In-person interventions demonstrated a large positive ES 1.177, 95% CI [.889, 1.464], compared with a smaller but significant ES of .424, 95% CI [.218, .629] for online interventions. While these findings suggest stronger effects for face-to-face delivery, external factors such as greater education interaction, engagement, or follow-up contact may partially contribute to this difference and should be considered when interpreting format-related effects.

Length of intervention significantly moderated the relationship between intervention and NK (Q = 12.029, $p = .002$). Interventions 7-12 weeks demonstrated the largest ES (1.562, 95% CI [1.023, 2.102]), followed by interventions longer than 13 weeks (ES = .998, 95% CI [.421, 1.574]). The smallest, though still significant, ES was observed in the shortest time frame of interventions lasting one to six weeks (ES = .601, 95% CI [.425, .777]).The stronger effects observed in intermediate-duration programs may reflect optimal balance between intensity and retention, whereas longer interventions may experience plateau effects or reduced engagements over time.

Validation status of NK survey used in studies also significantly influenced the relationship between intervention and NK (Q = 19.430, $p < .001$). Studies that did not use a validated survey showed a large positive ES (2.583; 95% CI [1.776, 3.390]), while those using validated surveys demonstrated a more moderate ES of .721, 95% CI [.535, .907]. The larger effects observed in studies without validated measured may indicate potential inflation of results and should therefore be interpreted with caution.

The Q-statistics for type of intervention (Q = 3.957, $p = .138$) and participant age (Q = .481, $p = .488$) were not significant moderators. Although subgroup ES were positive, the absence of statically significant moderation suggests these variables did not meaningfully explain between-study variability. This may reflect limited variability across included studies or insufficient statistical power to detect subgroup differences. Therefore, interpretations regarding intervention type and age should remain cautious.

Table 4. ES by Moderating Variable.

Moderator	Subgroup	Number of ES	ES	95% Lower CI	95% Upper CI	Q
Design	Double-arm	8	2.107	1.353**	2.861**	12.577**
	Single-arm	12	0.699	0.508**	0.891**	
Mode	In-person	16	1.177	0.889**	1.464**	17.479**
	Online	4	0.424	0.218**	0.629**	
Length	1–6 weeks	6	0.601	0.425**	0.777**	12.029*
	7–12 weeks	10	1.562	1.023**	2.102**	
	>13 weeks	4	0.998	0.421**	1.574**	
Validation Status of Survey	Yes	15	0.721	0.535	0.907	19.430**
	No	5	2.583	1.776	3.390	
Type	Lecture only	5	1.037	0.556**	1.518**	3.957
	Lecture + mixed methods	9	1.239	0.827**	1.651**	
	Mixed methods only, no lecture	6	0.697	0.343**	1.052**	
Age	University or older	9	0.959	0.608**	1.310**	0.481
	High school or younger	10	1.144	0.756**	1.532**	

**$p < .001$; *$p < .05$; ES = Effect Size; CI = Confidence Interval; Q = Chi-square Q statistic

Publication Bias

Although the funnel plot (Figure 3) appears asymmetrical and may visually suggest the presence of publication bias, Egger's regression intercept test (Table 5) was not statistically significant (t = .132, p = .897), indicating no strong evidence of directional bias. Complementing this, the trim-and-fill analysis (Table 6) imputed five potentially missing ES, which adjusted the pooled ES from 0.949 to 0.761. This reduction suggests that publication bias may have modestly inflated the observed ES.

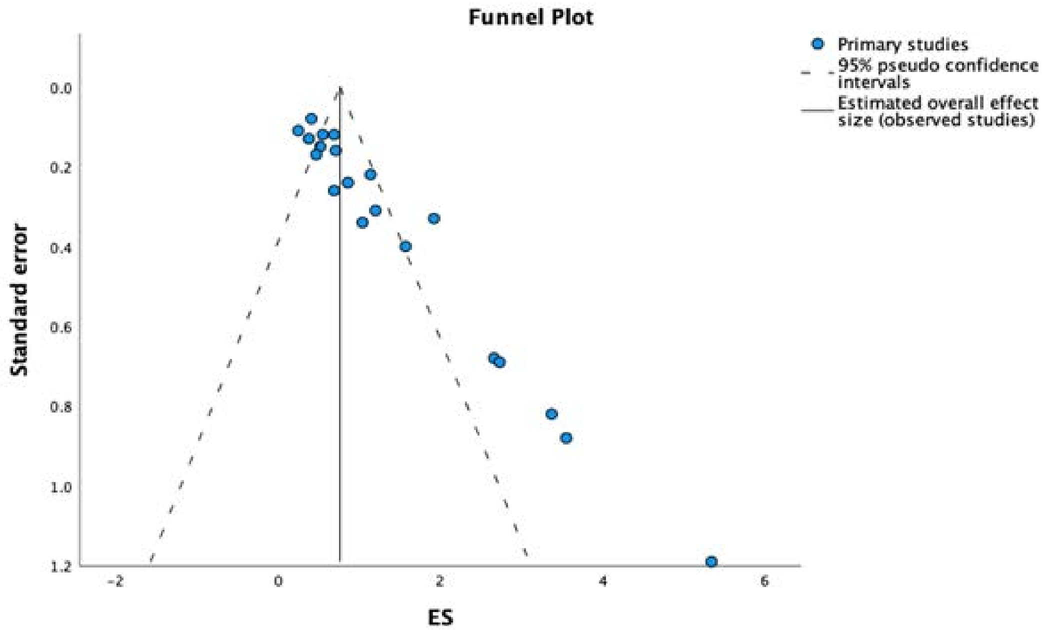

Figure 3. Funnel Plot.

Table 5. Egger's Regression-Based Test.

Parameter	Coefficient	SE	t	p-value (2-tailed)	95% Lower CI	95% Upper CI
(intercept)	.010	.0738	.132	.897	- .145	.165
SE	3.947	.4108	.9608	< .001*	3.084	4.810

*p < .05; SE = Standard Error

Table 6. Trim-and-Fill Analysis.

	Number of ES	ES	SE	Z	p-value (2-tailed)	95% Lower CI	95% Upper CI
Observed	20	.949	.1131	8.394	.000*	.728	1.171
Observed + imputed	25	.761	.1245	6.113	<.001*	.517	1.005

*p < .05; ES = Effect Size; SE = Standard Error; CI = Confidence Interval

Assessment of Bias and Quality

Further, the Downs and Black Checklist yielded a mean score ± SD of 18.93 ± 0.83, ranging from 17-20, considering the maximum score of 28. This indicates generally fair methodological quality across studies. No studies had quality scores outside of three SD from the mean; therefore, none were removed. Average scores for each domain were: (a) reporting (8.36 ± .63), (b) external validity (2.93 ± .27), (c) internal validity bias score (4.79 ± .43), (d) internal validity confounding score (2.64 ± .49) (e) power (.21 ± .43).

Certainty of Evidence

The GRADE assessment summarized in Table 7 evaluated the overall certainty of evidence for the outcome of nutrition knowledge. In this analysis, most studies were rated between low and moderate quality, with several randomized controlled trials contributing to higher confidence. Overall, the certainty of evidence was judged to be moderate, indicating a reasonable level of confidence in the pooled estimate of effect, though some concerns remain regarding sample size and imprecision.

Table 7. GRADE Assessment.

Quality Assessment							**Quality Rating**
Outcome	**Study Designs**	**Limitations (Risk of Bias)**	**Inconsistency**	**Indirectness**	**Imprecision**	**Considerations**	
Nutrition Knowledge	6 RCT; 3 quasi-experimental; 5 single-arm	No serious limitations: some risk due to non-randomized designs	No serious inconsistencies	No serious indirectness	Serious imprecision	Several large effect sizes observed; limited sample sizes; one pilot study	Moderate

Note: RCT = Randomized Control Trial

Discussion

This meta-analysis included 14 studies (20 effect sizes) and demonstrated a strong positive ES of nutrition education interventions on NK in athletes (ES = .949, z = 8.394, 95% CI [.728, 1.17]). Notably, the 95% PI ranged from 0.068 to 1.831, which does not include zero, suggesting that future similar studies are also likely to yield positive improvements in NK. This reinforces the robustness and generalizability of the observed effect and parallels the body of literature supporting that nutrition education interventions improve NK in athletes.[6-7, 26] The magnitude of the overall pooled ES and heterogeneity may partially be driven by a small number of extreme cases, as seen in the sensitivity analysis performed with one major outlier removed. Future studies should provide more detail on intervention context to explain unusually large ES.

The aim of this study was to measure overall ES of nutrition education interventions on NK in athletes and identify specific characteristics of nutrition education interventions that significantly influence NK and may be applied in future research or practical settings. The moderating relationships between study design (Q = 12.577), mode (Q = 17.479), and length (Q = 12.029) had significant differences across ES. Interestingly, the eight double-arm studies yielded larger ES compared to the twelve single-arm designs. While this may reflect the added value of comparison groups in detecting change, it may also relate to methodological differences such as larger sample sizes, greater intervention rigor, or differences in implementation fidelity. These interpretations remain tentative. Future research could directly compare sample size, program intensity, and methodological quality across study designs to better determine the source of these differences.

Additionally, the sixteen in-person effect sizes demonstrated a much larger ES (1.177) compared to the four online effect sizes (ES = .424), although the majority of studies analyzed (80%) included in-person interventions. However, this difference may not be attributable solely to format. Factors such as greater time-on-task, increased educator interaction, and follow-up contact may contribute to stronger outcomes in face-to-face settings. Additional education interventions using an online format are needed to make a more accurate comparison. Length of intervention was also a significant moderator between intervention and NK. Interventions lasting 7-12 weeks (10 effect sizes) demonstrated the largest positive ES (1.562, 95% CI [1.023, 2.102]) followed by interventions longer than 13 weeks (4 effect sizes; ES = .998, 95% CI [.421, 1.574]). Shorter interventions lasting 1-6 weeks (6 effect sizes) had the smallest, though still significant, ES of .601 (95% CI [.425, .777]). These patterns may reflect differences in intervention intensity or pedagogical load, with intermediate-length programs providing a balance between exposure and engagement. However, the unequal number of effect sizes across duration groups should be considered when interpreting these findings.

The ES for interventions that used a validated NK survey was significantly different across studies, and notably, studies using non-validated surveys (n = 5) had a much larger and greater mean ES (2.583) when compared to studies that used validated surveys (n = 15; ES = .721). One recommendation in previous systematic reviews was that researchers use validated survey measures to accurately assess effectiveness of nutrition education interventions.[7] The extremely large ES measured from several studies may indicate potential biases associated with the use of researcher-developed surveys. These outliers likely contributed to the overall heterogeneity and may reflect methodological artifacts such as the use of non-validated NK measures, small samples, or highly tailored interventions. The use of validated NK measures is essential to ensure accurate and comparable assessment across studies. This factor likely contributed to observed heterogeneity, alongside other potential sources such as population differences, variation in teaching content, and methodological quality. Future meta-regression analyses could help quantify the relative contribution to these variables. Further research is needed to understand why these differences occur and how they affect nutrition education programs in real life. Further, survey questions that undergo the necessary development and validation process are more supported to measure the desired outcome of NK and can be used as a standard to compare amongst different groups of athletes.

True ES for type of the intervention and age of athletes did not statistically differ across subgroups. There was no significant difference amongst interventions categorized as lecture, lecture and mixed methods, and mixed methods only. Age was also not a significant moderator of intervention effectiveness; although, this population lacks representation of older and professional athletes considering most of the sample included adolescent athletes.

The funnel plot suggests potential publication bias due to its asymmetries. Notably, the trim-and-fill results for adjusted ES still reflected a moderate to large positive effect of nutrition education interventions on NK (Hedges' g = 0.761) when analyzing for publication bias. Further, Egger's regression intercept test concludes no indication of strong directional bias. Although publication biases may be present, the true ES is likely still large but potentially lesser than the observed ES in this study.

The Downs and Black assessment averaged a fair score (18.93 $\pm$ .83) for methodological quality, which may reflect the lack of randomization and blinding across studies. The GRADE assessment rated the overall certainty of evidence for nutrition knowledge as moderate, suggesting that while the pooled findings are reliable, some caution is warranted due to small sample sizes and variability in study rigor. This moderate level of certainty supports the conclusion that nutrition education interventions effectively improve nutrition knowledge in athletes, though future studies should aim to strengthen methodological quality (e.g., larger, randomized studies) to enhance confidence in the evidence base.

A key limitation of this analysis is the age range and variation in competitive level among participants. Moreover, 73% of the individuals in this meta-analysis were high-school aged or younger which narrows the generalizability of this research. Notably, the single study with the participants ages 10-21 was only two weeks in duration,[20] which we can infer from duration results is less effective at increasing NK compared to longer interventions. Further developmental differences in cognitive maturity, autonomy over food choices, and prior nutrition exposure likely influence responsiveness to education interventions. For example, younger athletes may depend on parents for food provision, limiting the translation of knowledge into practice, whereas older or collegiate athletes may have greater independence and baseline knowledge. Additionally, professional or highly trained athletes may respond differently than high school athletes due to differences in motivations, resources, performance demands. Therefore, results should be interpreted within the context of participant age and competitive level, and future research should consider specific analyses factoring age and performance level in sport.

Nutrition education interventions are statistically influential to NK in athletes of all ages. Future interventions are recommended to last longer than seven weeks and explore both in-person and online modalities. In congruence with other literature recommendations, interventions are encouraged to implement validated nutrition knowledge measures to accurately assess interventions and teaching techniques. Further utilization of nutrition professionals, such as registered dietitians, should be considered when developing and conducting the intervention to improve validity. Discrepancies in the specific type of intervention regarding modality and age appropriation to the athlete population is recommended to be further explored.

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