

LJMU Research Online

Roberts, CJ, Newbury, JW, Foo, WL, Clark, CCT, Clarke, ND, Weldon, A and Gough, LA

The effect of a nutrition education programme on dietary intake and nutrition knowledge of trained young swimmers

<https://researchonline.ljmu.ac.uk/id/eprint/27595/>

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Roberts, CJ, Newbury, JW, Foo, WL, Clark, CCT, Clarke, ND, Weldon, A and Gough, LA (2025) The effect of a nutrition education programme on dietary intake and nutrition knowledge of trained young swimmers. *Performance Nutrition*. 1 (1). pp. 1-11. ISSN 3059-2933

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

RESEARCH

Open Access



The effect of a nutrition education programme on dietary intake and nutrition knowledge of trained young swimmers

Charlie J. Roberts^{1*}, Josh W. Newbury¹, Wee Lun Foo², Cain C. T. Clark¹, Neil D. Clarke¹, Anthony Weldon^{1,3} and Lewis A. Gough¹

Abstract

Background Nutrition is an important component for the developing swimmer and may be important to determine future success in the sport. Education is a key driver of facilitating changes in nutritional behaviour, but little is known about how this applies in practice among trained young swimmers. The purpose of this study therefore was to explore the impact of a nutrition education programme on dietary intake and nutrition knowledge in trained young swimmers. Fifteen participants aged 16 ± 3 years completed a 21-week education programme delivered via seven presentations and meal planning support. Energy, carbohydrate (CHO), protein, fibre, calcium, and iron intake were estimated in eight participants using the remote food photography method, alongside assessment of nutrition knowledge in fourteen participants using the Nutrition for Sport Knowledge Questionnaire, which were both conducted prior to and following the intervention.

Results There was no change in energy, protein, or fibre intake following the intervention. Absolute CHO intake ($p=0.021$), iron ($p=0.016$), and calcium intake ($p=0.022$) were significantly lower following the intervention. Nutrition knowledge was significantly greater following the intervention ($57.21 \pm 15.86\%$ vs. $72.14 \pm 12.44\%$; $p=0.004$) with greater nutrition knowledge positively associated with greater dietary fibre intake ($\beta=0.50$, $p=0.007$).

Conclusions These findings highlight the complex nature of facilitating changes in dietary intake in young swimmers and suggest that improvements in knowledge do not always translate to improved dietary practices.

Keywords Sports nutrition, Performance, Health, Wellbeing, Swimming, Young athlete

*Correspondence:

Charlie J. Roberts
Charlie.roberts@bcu.ac.uk

¹Human Performance and Health Research Group, Department of Life and Sport Sciences, Birmingham City University, Birmingham, UK

²Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

³Aston Villa Foundation, Aston Villa Football Club, Birmingham, UK



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Introduction

In competitive swimming, athletes will typically progress from ‘learn to swim’ programmes into formal training between ages 8–10 years, allowing them to develop optimal stroke techniques, physical attributes, and racing skills to compete at an elite standard by adolescence [1]. By 16 years of age, highly trained swimmers will likely be completing 8–10 training sessions·week^{−1} [2, 3], akin to their Olympic counterparts [4] thereby demonstrating early specialisation in swimming. Furthermore, adolescence is a time of significant growth and maturation of tissues and physiological systems, with ~ 50% of adult height and ~ 20% of adult weight being achieved during this time [5]. Combined, these high training volumes, energy requirements, and rates of growth increase the metabolic demands and nutrient requirements of youth athletes [6, 7]. It is suggested total energy expenditure, albeit in a slightly older cohort (mean age: 19), can be ~ 5600 kcal per day over a five-day training period [8]. This can be problematic, as young swimmers experience congested schedules, where they attempt to balance mandatory education, potential part-time work, and social obligations [9], leaving little time to prepare and eat foods to meet their energy requirements. Furthermore, relationships with food are often established during this time and can influence an individuals’ food choices and dietary habits into adulthood [10], with suboptimal education and support potentially leading to inadequate dietary choices and poor nutrition habits. Considering these factors, this is an appropriate opportunity to educate young swimmers on nutrition to support their high energy requirements and to establish life-long healthy nutrition habits.

Supporting changes in dietary intake is complex due to various factors affecting an individual’s food choice. For example, biological processes can cause changes in appetite and hunger, whilst societal and environmental factors such as culture and religion, cost of food, the influence of caregivers, family, education, and friends can also influence dietary habits [11–13]. Notably, improving nutrition knowledge has shown some improvements in dietary intake, particularly of fruits and vegetables [14]. In athletes, a systematic review has reported weak to moderate positive correlations between nutrition knowledge scores and dietary intake for both health and performance across various cohorts [15] and weak positive associations between nutrition knowledge and diet quality were found in elite athletes [16]. Focusing on swimming, a

positive correlation was observed among 52 adolescent swimmers regarding nutrition knowledge and healthy food habits [17]. However, despite nutrition knowledge being an influencing factor for athletes making positive food choices and dietary habits, it is reported the nutrition knowledge of young swimmers remains poor [18–20]. Accordingly, further research is required to assess the current effectiveness of education frameworks delivered to swimmers, and whether these produce worthwhile changes in dietary intakes to support health and performance.

Improving nutrition knowledge may support enhanced dietary intake and subsequent growth, development, and wellbeing in young swimmers whilst optimising performance, recovery, and injury mitigation. Accordingly, nutrition education support is commonplace in sporting organisations. Previous studies have explored the impact of short-structured education interventions aimed at young competitive swimmers on changes in nutrition knowledge. Foo et al. (2021) [19] found a seven-week structured education framework, consisting of weekly 30-minute classroom-based sessions delivered by an undergraduate student, improved sport nutrition knowledge by 8% in national and international adolescent swimmers in the UK. The authors did not measure dietary intake before or after the intervention unfortunately, therefore the translation to dietary practices is unknown. Additionally, Philippou et al. (2017) [21] found that one half-day nutrition workshop delivered by dieticians and a medical doctor, alongside guided supermarket tours and instructions on interpreting food labelling and a two-hour session for parents improved adherence to Mediterranean diet recommendations for up to six weeks after the intervention in national-level young swimmers. Whilst the study may show a likely improvement in the diet quality, this change does not suggest that swimmers were consuming adequate energy and nutrients to support their needs as athletes. No studies have explored how sports nutrition education may influence the intake of nutrients specifically for athletes to meet best-practice recommendations in the literature and used in practice [1] nor wider nutritional considerations for health, wellbeing, and development in young athletes [10]. As such, the aims of the study were to investigate the effect of the sports nutrition education programme on (1) energy, carbohydrate, protein, fibre, calcium, and iron intake and (2) sports nutrition knowledge of trained young swimmers.

Table 1 Participant characteristics

	Female (n = 10)	Male (n = 5)	Combined (n = 15)
Age (years)	16 ± 2	16 ± 4	16 ± 3
Body mass (kg)	60.1 ± 10.3	66.3 ± 14.8	62.2 ± 11.8
Height (cm)	169.1 ± 9.0	177.0 ± 10.9	171.8 ± 10.1

Methods

Participants

Fifteen athletes from a British high-performance swimming club volunteered to take part in this study (Table 1). Participants had a mean of 645 ± 84 World Aquatic

points for their specialist swimming event [21]. All participants and primary caregiver for participants < 18 years old provided informed consent before the study commenced. A convenience sample was justified due to the rarity of the cohort, the applied nature of the study, and the use of knowledge and dietary intake data, which is novel compared to previous education research in swimming. The Birmingham City University ethics committee (Newbury/7596/R(B)/2020/Aug/HELS FAEC) granted ethical approval for the study.

Table 2 Overview of the sport nutrition education framework

Session	Topic	Learning Outcomes and Skills
1	Energy, protein, and body composition	• Importance of body composition for training and competition • Energy balance for body composition manipulation • Protein for optimal body composition changes • Identification of high protein foods
2	Pre-training nutrition	• Carbohydrate type, timing, and requirements to support training performance and avoid gastrointestinal discomfort • Timing of fats and protein to best support training performance • Importance of hydration • Identification of carbohydrate foods to meet individual requirements
3	Intra-training nutrition	• The role of intra-workout carbohydrate to support training performance • Hydration strategies to support training performance • Planning personal hydration strategies
4	Post-training nutrition	• Carbohydrates, protein, and fluids to support recovery and adaptation • Timing and importance of dietary fats within the diet • Post-workout meal planning to support personal carbohydrate and protein requirements
5	Nutritional supplements	• Nutritional ergogenic aids to support training and competition performance • Dietary supplements to support health • Regulation and safety of nutritional supplements
6	Competition nutrition	• Nutritional demands of multi-day swimming competitions • Pre-race fuelling and hydration during competition • Post-race glycogen replenishment and recovery • Food preparation and informed restaurant choices to support individual requirements
7	Nutrition during taper	• Nutritional demands during periods of reduced training loads • Strategies to reduce energy intake during taper

Sport nutrition education

The sports nutrition education programme was based on a previous framework for highly trained adolescent swimmers [19]. This involved the delivery of seven nutrition topics (Table 2) adopting a scaffolding approach by two members of the research team, and two level 6 undergraduate students from Birmingham City University with each session overseen by a qualified nutritionist on the Sport and Exercise Nutrition Register (SENr) and a member of the research team. The nutrition sessions lasted ~ 30 min and commenced every three weeks over a 21-week period, starting in January and ending prior to end of season competitions in July. All education sessions were classroom-based, taking place in a seminar room at the swimming club's training facilities before an evening training session (time: 17:30–18:00). Education was delivered via PowerPoint presentation, with opportunities for discussion and questions throughout. Meal planning activities to achieve the recommended CHO and protein intakes were included in sessions 1, 2, 3, 4, and 6 to supplement learning.

Dietary intake

Participants completed a three-day remote food photography method food diary in line with previously validated methods in young athletes [23, 24]. This required participants to photograph all meals, snacks, beverages, and supplements on three distinct occasions: (a) on a morning training day (05:00–07:00), (b) on an evening training day (18:00–20:00), and (c) on a rest day. To detail the amount of food/drink consumed, photographs were required to be taken and sent by instant messaging (WhatsApp, Mountain View, CA, USA) to a member of the research team (JN) before being consumed. To standardise food and drink portions, participants were given a paper 1 × 1 cm grid placemat to include in each photograph, and measurement shakers were asked to be used for fluids (Nyström et al., 2016). Following each photograph, further clarification of product brand, cooking methods, portion size, and ingredients was immediately requested using text or voice recordings. After the three days were complete, the lead researcher inputted and analysed food intakes with a dietary analysis software package (Nutritics 3.06, Dublin, Ireland). Any items unavailable via the Nutritics database were manually inputted using packaging labels. The mean of the three days was used to estimate the typical dietary intake of swimmers over the three sampling time points as per previous recommendations [22]. All measurements were completed on the same day of the week in a competition cycle. Training volume remained similar (~ 40–45 km/week, 6–8 swim and 1–3 gym sessions) and was outside of any taper windows or competitions to maintain similar training conditions at each time point.

The assessment method validity and the inter-rater reliability of the researcher analysing food diaries have been previously reported [3]. This involved the analysis of eight meals with known energy and macronutrient content on two separate occasions, with one of the meals analysed on another 20 separate occasions. Intra-rater reliability was determined to be 'excellent', with coefficient of variations (CV) of 2.7%, 4.8%, 3.9% and 1.2% for energy, carbohydrate, protein, and fat content, respectively. The validity of the analysis method was assessed using Pearson's correlation coefficient and by the CV of error: energy intake ($r = 0.947$, $p < 0.001$, $CV = 2.0\%$), carbohydrate ($r = 0.972$, $p < 0.001$, $CV = 3.5\%$), protein ($r = 0.914$, $p < 0.001$, $CV = 6.4\%$), fat ($r = 0.977$, $p < 0.001$, $CV = 1.0\%$).

Sport nutrition knowledge

Two weeks before the commencement of the sport nutrition education programme, participants completed validated sport nutrition knowledge questionnaire (Nutrition for Sport Knowledge Questionnaire; NSKQ) [25, 26]. The questionnaire was modified to be delivered as a quiz (Google Forms, Google LLC, Mountain View, CA, USA), allowing convenient dissemination and completion by young athletes. The quiz involved 87 multiple-choice questions over six categories: weight management (12 questions), macronutrients (30 questions), micronutrients (13 questions), sports nutrition (12 questions), supplements (12 questions), and alcohol (8 questions), with each correct answer scoring 1 point. The total points scored out of a maximum of 87 were used to quantify nutrition knowledge. The NSKQ has demonstrated test-retest reliability ($r = 0.92$), construct validity via significant differences in scores between nutrition and non-nutrition students ($p < 0.001$), and content validity via qualitative analysis within sports dieticians [26]. All swimmers completed the questionnaire in a 30-minute land-training session to ensure answers were not discussed with other swimmers or parents. The NSKQ was repeated two weeks after the final nutrition education session to identify potential changes in nutrition knowledge.

Statistical analysis

We utilized linear mixed modelling (LMM) to examine the effects of group (male vs. female), time (pre- vs. post-intervention), and their interaction on various dietary intake variables (absolute energy intake ($\text{kcal}\cdot\text{day}^{-1}$), relative energy intake ($\text{kcal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$), absolute CHO intake ($\text{g}\cdot\text{day}^{-1}$), relative CHO intake ($\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$), absolute protein intake ($\text{g}\cdot\text{day}^{-1}$), relative protein intake ($\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$), fibre intake ($\text{g}\cdot\text{day}^{-1}$), calcium intake ($\text{mg}\cdot\text{day}^{-1}$), and iron intake [$\text{mg}\cdot\text{day}^{-1}$]) following the structured education programme. Individual participants

were included as a random intercept to account for the repeated measures inherent in the study design. Prior to the linear mixed modelling analyses, paired samples t-tests were performed to assess changes in nutrition knowledge, between pre- and post-intervention time points.

Model parameters for the LMMs were estimated using maximum likelihood, aligning with current recommendations for model comparison. Satterthwaite's method was employed to approximate degrees of freedom and conduct significance testing for the fixed effects. Model fit was assessed using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The proportion of variance explained by fixed and random effects was evaluated using Nakagawa's R^2 , with both marginal R^2 (representing fixed effects only) and conditional R^2 (representing fixed and random effects) calculated and reported. Both Linear Models (LM) and Linear Mixed Models (LMM) were fitted, and results are presented.

In instances where the fixed effects in the overall LMM indicated a statistically significant ($p < 0.05$) or marginally significant ($p < 0.1$) interaction effect, post-hoc pairwise comparisons were conducted using estimated marginal means with Tukey's adjustment for multiple comparisons. Additionally, Cohen's d effect sizes were computed for each contrast using the residual standard deviation of the model. Effect sizes were interpreted as trivial (< 0.2), small ($0.2\text{--}0.6$), moderate ($0.6\text{--}1.2$), large ($1.2\text{--}2.0$), and very large (≥ 2.0) [27].

Statistical significance was accepted, a priori, at $p < 0.05$, and 95% confidence intervals (CIs) were reported where applicable. Model assumptions, including normality of residuals and homoscedasticity, were visually inspected using diagnostic plots. All statistical analyses were conducted using R (R Core Team (2018). R: A Language and environment for statistical computing. [Computer software; retrieved from <https://cran.r-project.org/>), with the lme4, lmerTest, performance, and emmeans packages.

Results

Energy intake

Eight participants recorded dietary intake on each day for both pre- and post-intervention and were therefore included in the analysis, with results for specific nutrients presented in Table 3. LMM was performed for each dependent dietary intake variable, while controlling for nutrition knowledge and accounting for within-participant variability. Full model parameters for each variable are detailed in the individual model outputs. Accordingly, no main effects for group or time, or interaction effects of group $\times$ time were evident for absolute energy or relative energy intake. Nutrition knowledge was also not a significant predictor for either variable.

Table 3 A statistical summary of energy intake, macronutrients, fibre, calcium, and iron before and after the education intervention

Variable	Group	Pre-Intervention	Post-intervention	Change (%)	Main Effect of Group (β , p -value, 95% CI)	Main Effect of Time (β , p -value, 95% CI)	Interaction (β , p -value, 95% CI)	Mar- ginal R^2	Con- di- tion- al R^2	Explanatory power of ran- dom effects (Change in R^2)
Energy (kcal·day ⁻¹)	F	2185.5 ± 451.4	2121.8 ± 571.6	-2.9						
	M	3338.6 ± 927.2	2249.5 ± 254.8	-32.6	$\beta = 331.13, p = 0.466, [-580.21, 1381.78]$	$\beta = -199.29, p = 0.239, [-645.32, 142.05]$	$\beta = -195.09, p = 0.535, [-900.96, 503.00]$	0.210	0.799	0.589
Relative energy (kcal·kg ⁻¹ ·day ⁻¹)	Overall	2473.7 ± 743.8	2153.75 ± 496.1	-12.9						
	F	37.5 ± 9.9	34.6 ± 9.4	-7.7						
CHO (g·day ⁻¹)	M	43.4 ± 0.1	27.9 ± 9.8	-35.7	$\beta = 5.97, p = 0.517, [-13.06, 26.30]$	$\beta = -2.81, p = 0.305, [-9.44, 2.60]$	$\beta = -5.63, p = 0.260, [-16.15, 4.81]$	0.088	0.87	0.782
	Overall	39.0 ± 8.2	32.9 ± 9.3	-15.5						
Relative CHO (g·kg ⁻¹ ·day ⁻¹)	F	265.7 ± 44.3	230.6 ± 41.6	-13.2						
	M	405.8 ± 153.4	248.0 ± 9.0	-38.9	$\beta = 13.39, p = 0.734, [-67.61, 98.04]$	$\beta = -49.96, p = 0.021^*, [-91.69, -11.04]$	$\beta = -8.48, p = 0.833, [-96.57, 79.41]$	0.359	0.627	0.268
Protein (g·day ⁻¹)	Overall	300.8 ± 94.7	235.0 ± 36.2	-21.9						
	F	4.6 ± 1.2	3.8 ± 0.8	-17.8						
Relative protein (g·kg ⁻¹ ·day ⁻¹)	M	5.2 ± 0.6	3.0 ± 0.8	-41.4	$\beta = 0.25, p = 0.799, [-1.80, 2.36]$	$\beta = -0.79, p = 0.063, [-1.63, 0.01]$	$\beta = -0.34, p = 0.653, [-1.99, 1.30]$	0.229	0.751	0.522
	Overall	4.7 ± 1.0	3.6 ± 0.8	-24.3						
Fibre (g·day ⁻¹)	F	100.6 ± 32.7	98.7 ± 24.4	-1.9						
	M	163.8 ± 37.9	144.7 ± 41.0	-11.7	$\beta = 26.56, p = 0.303, [-26.69, 81.01]$	$\beta = -9.95, p = 0.088, [-22.13, 0.93]$	$\beta = 38.29, p = 0.003^{**}, [18.56, 57.95]$	0.516	0.967	0.451
Calcium (mg·day ⁻¹)	Overall	116.4 ± 42.7	110.2 ± 33.5	-5.4						
	F	1.7 ± 0.6	1.6 ± 0.4	-6.0						
Iron (mg·day ⁻¹)	M	2.1 ± 0.1	1.8 ± 0.9	-14.6	$\beta = 0.39, p = 0.404, [-0.58, 1.38]$	$\beta = -0.19, p = 0.099, [-0.43, 0.03]$	$\beta = 0.37, p = 0.076, [-0.03, 0.78]$	0.318	0.941	0.623
	Overall	1.8 ± 0.5	1.7 ± 0.5	-8.5						
Relative energy (kcal·kg ⁻¹ ·day ⁻¹)	F	25.5 ± 7.5	27.5 ± 10.1	8.1						
	M	37.4 ± 8.0	24.3 ± 2.4	-35.0	$\beta = -1.29, p = 0.838, [-14.49, 15.19]$	$\beta = -4.12, p = 0.268, [-11.78, 4.01]$	$\beta = -11.48, p = 0.208, [-28.66, 5.68]$	0.529	0.561	0.032
Calcium (mg·day ⁻¹)	Overall	28.5 ± 9.0	26.7 ± 8.7	-6.1						
	F	844.9 ± 233.4	746.9 ± 279.1	-11.6						
Iron (mg·day ⁻¹)	M	1921.3 ± 571.3	878.1 ± 570.1	-54.3	$\beta = 664.51, p = 0.022^*, [131.46, 1210.42]$	$\beta = -104.47, p = 0.380, [-355.55, 137.13]$	$\beta = -138.29, p = 0.570, [-664.66, 387.45]$	0.527	0.768	0.241
	Overall	1114.0 ± 577.8	779.7 ± 325.2	-30.0						
	F	15.0 ± 5.3	11.5 ± 2.2	-23.2						

Table 3 (continued)

Variable	Group	Pre-Intervention	Post-intervention	Change (%)	Main Effect of Group (β , p -value, 95% CI)	Main Effect of Time (β , p -value, 95% CI)	Interaction (Group x Time) (β , p -value, 95% CI)	Marginal R^2	Con-dition-al R^2	Explanatory power of random effects (Change in R^2)
	M	20.1 $\pm$ 6.0	14.6 $\pm$ 3.0	-27.5	$\beta = -1.02$, $p = 0.785$, [-8.73, 6.89]	$\beta = -4.98$, $p = 0.016^*$, [-8.84, -1.27]	$\beta = -0.01$, $p = 0.998$, [-8.32, 8.29]	0.334	0.614	0.28
	Overall	16.3 $\pm$ 5.5	12.3 $\pm$ 2.6	-24.5						

β : Beta coefficient, the estimated change in the dependent variable for a one-unit change in the predictor variable, p -value: the probability of observing the given result, or a more extreme one, if the null hypothesis were true, 95% CI: the range of values within which the true effect is expected to lie with 95% confidence, based on the sample data, Marginal R^2 : the proportion of variance in the dependent variable explained by the fixed effects alone in a mixed-effects model, Conditional R^2 : the proportion of variance in the dependent variable explained by both fixed and random effects in a mixed-effects model, Explanatory power of random effects (Change in R^2): the increase in variance explained when random effects are added to the model, calculated as the difference between conditional R^2 and marginal R^2 , M: denotes Male, F: denotes Female, g·day⁻¹: denotes grams per day, mg·day⁻¹: denotes milligrams per day, g·kg⁻¹·day⁻¹: denotes grams per kilogram per day, mg·kg⁻¹·day⁻¹: denotes milligrams per kilogram per day, kcal·day⁻¹: denotes kilocalories per day, kcal·kg⁻¹·day⁻¹: denotes kilocalories per kilogram per day, *: denotes statistical significance at $P < 0.05$

CHO intake

For absolute CHO intake, we noted a significant main effect of time ($\beta = -49.96$, $p = 0.021^*$, 95% CI: [-91.69, -11.04]), indicating a significant overall decrease from pre- to post-intervention. The model explained 35.9% of the variance by fixed effects and 62.7% by fixed and random effects. Post-hoc pairwise comparisons for absolute CHO did not reveal significant differences for the time effect within groups (Female: difference = 49.96, $p = 0.062$, $D = 1.97$, 95% CI: [-0.39, 4.34]; Male: difference = 58.45, $p = 0.244$, $D = 2.31$, 95% CI: [-2.02, 6.64]) or between groups at each time point (Time 1: difference = -13.39, $p = 0.791$, $D = -0.53$, 95% CI: [-4.65, 3.59]; Time 2: difference = -4.91, $p = 0.923$, $D = -0.19$, 95% CI: [-4.33, 3.94]).

For relative CHO intake, no main effect of time was noted ($\beta = -0.79$, $p = 0.063$, 95% CI: [-1.63, 0.01]) nor for group x time ($\beta = -0.34$, $p = 0.076$, 95% CI: [-1.99, 1.30]). No significant main effect of group or nutrition knowledge was evident. The model explained 22.9% of the variance by fixed effects and 75.1% by fixed and random effects. Post-hoc pairwise comparisons for relative CHO intake did not reveal significant differences for time effects within groups (Female: difference = 0.79, $p = 0.154$, $D = 1.66$, 95% CI: [-0.87, 4.19]; Male: difference = 1.13, $p = 0.253$, $D = 2.38$, 95% CI: [-2.16, 6.90]) or between groups at each time point (Pre-intervention: difference = -0.25, $p = 0.841$, $D = -0.53$, 95% CI: [-6.01, 4.96]; Post-intervention: difference = 0.09, $p = 0.943$, $D = 0.19$, 95% CI: [-5.32, 5.69]).

Protein intake

For absolute protein intake, we observed no main effect of time ($\beta = -9.95$, $p = 0.088$, 95% CI: [-22.13, 0.93]). A significant interaction effect of group x time was evident ($\beta = 38.29$, $p = 0.003^{**}$, 95% CI: [18.56, 57.95]) indicating that the effect of time on protein intake is different between male and female groups. However, no significant main effect of group was observed. The model explained 51.6% of the variance by fixed effects and 96.7% by fixed and random effects. Post-hoc pairwise comparisons for absolute protein intake demonstrated that, for males, there was a significant decrease in absolute protein intake from pre- to post-intervention (difference = -28.34, $p = 0.035^*$, $D = -4.99$, 95% CI: [-10.42, 0.44]), but was not significant in females (difference = 9.95, $p = 0.181$, $D = 1.75$, 95% CI: [-1.11, 4.62]). Moreover, at pre-intervention, there was no significant difference between females and males (difference = -26.56, $p = 0.382$, $D = -4.68$, 95% CI: [-16.31, 6.95]), whilst at post-intervention, females had significantly lower absolute protein intake than males (difference = -64.86, $p = 0.048^*$, $D = -11.43$, 95% CI: [-24.58, 1.73]).

For relative protein intake, no main effect of time ($\beta = -0.19$, $p = 0.099$, 95% CI: [-0.43, 0.03]. or interaction

effect of group $\times$ time was noted ($\beta = 0.37$, $p = 0.076$, 95% CI: $[-0.03, 0.78]$). No significant main effect of group or nutrition knowledge evident. The model explained 31.8% of the variance by fixed effects and 94.1% by fixed and random effects. Post-hoc pairwise comparisons for relative protein intake did not reveal significant differences for time effects within groups or between groups at each time point.

Fibre intake

For fibre, a significant main effect of nutrition knowledge was found ($\beta = 0.50$, $p = 0.007^{**}$, 95% CI: $[-0.07, 0.80]$), indicating a positive association between higher nutrition knowledge and fibre intake. However, no significant main effects for group or time, or interaction effects of group $\times$ time were evident. Post-hoc pairwise comparisons for fibre did not reveal any significant differences for time effects within groups or group differences at each time point.

Iron intake

For iron, a significant main effect of time was also observed ($\beta = -4.98$, $p = 0.016^{*}$, 95% CI: $[-8.84, -1.27]$), reflecting a significant decrease from pre- to post-intervention. The model explained 33.4% of the variance by fixed effects and 61.4% by fixed and random effects. Post-hoc pairwise comparisons for iron did not reveal significant differences for the time effect within groups (Female: difference = 4.98, $p = 0.051$, $D = 2.08$, 95% CI: $[-0.32, 4.47]$; Male: difference = 4.99, $p = 0.291$, $D = 2.08$, 95% CI: $[-2.21, 6.37]$) or between groups at each time point (Pre-intervention: difference = 1.02, $p = 0.832$, $D = 0.42$, 95% CI: $[-3.70, 4.55]$; Post-intervention: difference = 1.03, $p = 0.831$, $D = 0.43$, 95% CI: $[-3.72, 4.58]$).

Calcium intake

For calcium, we found a significant main effect of group ($\beta = 664.51$, $p = 0.022^{*}$, 95% CI: $[131.46, 1210.42]$), with males exhibiting significantly higher calcium intake compared to females. The model explained 52.7% of the variance by fixed effects and 76.8% by fixed and random effects. Post-hoc pairwise comparison between groups at pre-intervention (difference = -665 , $p = 0.055$, $D = -4.37$, 95% CI: $[-9.48, 0.74]$), or post-intervention showed no significance (difference = -526 , $p = 0.124$, $D = -3.46$, 95% CI: $[-8.37, 1.45]$). The change over time for males (Difference = 769, $p = 0.0183^{*}$, $D = 5.06$, 95% CI: $[0.07, 10.05]$) indicated a significant decrease in calcium intake.

Sports nutrition knowledge

Fourteen participants completed both pre- and post-intervention nutrition knowledge questionnaires. Descriptive statistics indicated that mean nutrition knowledge increased from pre- to post-test. At

baseline, participants had a mean score of $57 \pm 16\%$, which increased to $72 \pm 12\%$ post-intervention. A paired-samples t-test confirmed this improvement was statistically significant ($p = 0.004$, 95% CI $[24.3, 5.55]$, with a large effect size ($d = 0.92$, 95% CI $[0.28, 1.54]$), indicating a meaningful increase in nutrition knowledge following the intervention.

Discussion

This study explored the influence of a sports nutrition education programme on dietary intake and nutrition knowledge in trained young swimmers. Following the nutrition education intervention, relative energy, absolute and relative CHO, calcium, and iron intake were all significantly lower, whereas absolute energy, absolute and relative protein, and fibre intake were not different. These changes were found despite an increase in nutritional knowledge following the sports nutrition education intervention. It is unclear therefore whether this approach to nutrition education is effective to change behaviour, prompting further research.

Mean relative CHO intakes following the intervention were $3.6 \pm 0.8 \text{ g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ and therefore did not meet a minimum of $6.0 \text{ g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ for moderate-high intensity exercise programming $\geq 1 \text{ h}$ per day [28]. Previous research in young swimming [29], football [30], and tennis [31] athletes in the UK also report a lack of guidelines being met. The CHO intake in the current study was highly variable with one participant dramatically reducing CHO intake post-intervention, whilst others presented more subtle reductions (Fig. 1). The importance of CHO for competitive swimmers is well-recognised, with high-volume training blocks likely to result in significant muscle glycogen depletion [32], and therefore, suboptimal intake can impair swimming performance [1]. A $\sim 10\%$ reduction in dietary CHO intake over 3 days significantly reduced the time to complete a 364 m swimming time trial [33]. However, low CHO intake for 3 days did not influence swimming economy at 50–70% VO2max in recreational swimmers [34]. These highlight the importance of considering individual variability in training and general life schedules, which may influence the results observed for overall intake. Given that swimmers are recommended to periodise CHO intake around training and competition [35, 36], a lower average relative CHO intake may be reflective of lower training volumes and/or intensities of training sessions, however may also relate to logistical issues with consuming adequate food and beverages around school and training, or due to food provision from their caregivers. As such, future research should explore the impact of nutrition education on the periodisation of dietary intake both within and between-day, with explicit reference to training sessions and/or competitions. Additionally, protein intake

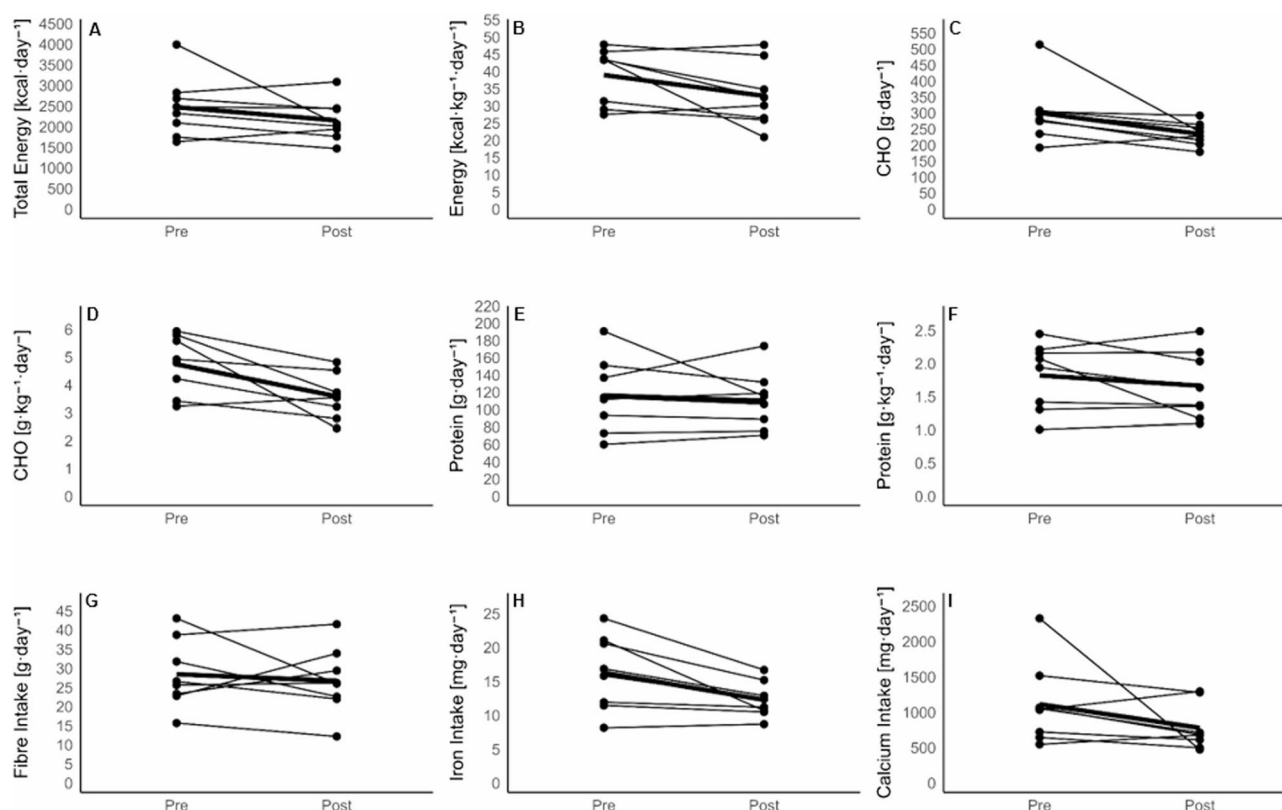


Fig. 1 Individual changes in dietary intake between pre- and post-intervention timepoints. **A** Absolute energy intake; **B** Relative energy intake; **C** Absolute carbohydrate (CHO) intake; **D** Relative CHO intake; **E** Absolute protein intake; **F** Relative protein intake; **G** Fibre intake; **H** Iron intake; **I** Calcium intake. There was a significant main effect of group for calcium intake, significant main effect of time for CHO and iron, and significant group $\times$ time interaction for protein

was not significantly different, which met the best practice recommendation of $1.2\text{--}2.0\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ [37, 38] following the intervention. Whilst there was no significant change following the education session delivery, dietary protein intake was already estimated to be above typical best-practice sports nutrition guidelines for athletes. As such, no significant change is unlikely to be detrimental however within the context of a reduced energy intake, it is important for athletes to be mindful that carbohydrate intake is not compromised if protein intake remains elevated [39].

Whilst meeting nutritional recommendations for exercise performance is important for competitive swimmers, the requirements for health, wellbeing, growth, and maturation in young swimmers cannot be understated [10]. In our study, fibre intake did not change. However, this was consistent with the UK government recommendation and best practice sports nutrition recommendations to consume $\geq 30\text{ g}$ fibre daily [39, 40]. Whilst fibre intake in our study was reported to meet recommendations, micronutrient intake appeared to be suboptimal. Calcium intake was significantly lower following the intervention (780 mg), potentially due to an overall reduction in energy intake, and did not meet

the daily recommendation for both males (1000 mg) or females (800 mg) between the ages of 11–18 [37]. This is similar to the findings of a longitudinal study in female adolescent swimmers, with $527 \pm 201\text{ mg}$, $770 \pm 25\text{ mg}$, and $649 \pm 247\text{ mg}$ reported across 3 years [41]. For those aged 11–18, daily iron intakes of 14.8 mg and 11.3 mg are recommended for females and males, respectively [39], with our data showing females did not meet recommendations following the intervention (11.5 mg) whilst males exceeded these (14.6 mg) which may relate to specific food choices between groups. Iron deficiency is often commonly reported in young athletes [42] and failure to meet daily recommendations for iron, alongside presentation of iron depletion and low haemoglobin common for both male and female adolescent athletes [43]. Both calcium and iron have been highlighted as the main micronutrients whereby insufficiency is observed in swimmers, typically limited to female athletes [1]. Given the findings of our study, practitioners should ensure that health-related components are included in educational materials for young athletes, particularly given the important role of both calcium and iron in growth, maturation and development.

Sports nutrition knowledge scores were significantly greater following the intervention in our study. This is unsurprising, given that nutrition education programmes are typically delivered based on targeting knowledge levels, which are expected, and sometimes assumed, to translate into improved dietary practices [44]. A systematic review of 32 interventions representing 2180 participants reported that most ($n = 30$) studies reported a significant improvement in nutrition knowledge scores following education delivery [45]. In young competitive swimmers, a previous study explored the impact of a seven-week intervention comprised of weekly 30-minute education sessions on changes in nutrition knowledge, with an 8.3% increase in nutrition knowledge scores observed [19]. Improvements in nutrition knowledge have also been observed in adolescent competitive swimmers in Cyprus following a single half-day nutrition education session, as well as a separate session for primary caregivers [21]. However, both studies used different methods for assessing nutrition knowledge and delivering nutrition education compared to our study. This is a recognised limitation of the literature exploring the impact of nutrition education sessions [46], and as such, contextualising our results to the broader evidence base is challenging. Additionally, knowledge is only one component that might influence dietary intake [11, 46] and young athletes particularly might not have full autonomy over food choices given the important role that other stakeholders such as caregivers play in procuring, preparing, and providing food and meals [12] which may have influenced the changes in dietary intake observed in this study. As a result, ensuring the athletes wider network is educated on appropriate nutritional practices is essential including parents/caregivers and coaches.

Our study provides novel data on the impact of structured nutrition education on changes in dietary intake in the context of best-practice sports nutrition recommendations for trained young swimmers. However, this study has the following limitations for the reader to consider when interpreting the results: (1) The use of dietary analysis is prone to measurement error and bias in the information provided by participants, due to the self-reported nature of the method [24] and the limited number of monitoring days is unlikely to be reflective of habitual dietary intake; (2) Although intra-rater reliability was reported for the analysis of dietary intake, variability in how food photographs and descriptions are interpreted by different individuals can be significant [47], which may compromise the accuracy of specific nutritional values reported. However, given the applied nature of the study and the young population, the remote food photography method represented the most practical way of assessing these outcomes; (3) Testing was conducted within one club from a convenience sample

with no power calculation conducted prior to testing, and we were unable to include a control group due to the applied nature of the study. As such, broader generalisation of the findings into other populations are likely only appropriate for similar sporting environments as per this study and the findings must be interpreted appropriately as dietary intake may have habitually changed between data collection periods; (4) the focus of the study on young athletes, without consideration for caregivers who likely have more influence over their food choices and dietary intake, presents a limitation. It is acknowledged that caregivers play a crucial role in purchasing, preparing, and providing food and meals, and supporting the development of eating habits, consumption patterns, and autonomy around dietary intake in children and adolescents [48]. Previous research in caregivers of academy football players suggest poor sports nutrition knowledge levels [12, 49] and factors that influence their ability to support a young athletes' nutritional requirements such as time, finances, and individual preferences [11] which must be considered when interpreting the changes in dietary intake of swimmers in the present study; (5) these findings must be interpreted in the context of the specific times around the swimming calendar as factors such as preparing and engaging in competitions may influence dietary intake; (6) we acknowledge that the questionnaire used in the present study (NSKQ) is not validated in a swimming population, rather, within a larger athletic cohort [26] and that sub-analysis of individual sections in the NSKQ could provide further context and justification for targeted support provision in future research and practice.

In conclusion, the delivery of a nutrition education programme resulted in a significant decrease in CHO, calcium, and iron intake, a significant increase in nutrition knowledge, and no change in energy, protein, or fibre intake in trained young swimmers. The findings highlight the benefit of a sports nutrition education programme on young athletes' nutrition knowledge; however, nutritional status was not positively influenced and as such, education programmes may not translate to favourable behaviour change. The inclusion of individual participants as a random intercept in the present allowed for crucial insights into the role of individual differences. For several variables, notably absolute energy (Conditional R^2 : 0.799 vs. Marginal R^2 : 0.210), relative energy (0.870 vs. 0.088), absolute protein (0.967 vs. 0.516), and relative protein intake (0.941 vs. 0.318), the substantial difference between the conditional and marginal R^2 values highlights that a very large proportion of the total variance in these dietary intakes is attributable to unique participant-specific factors that are not explained by the fixed effects (i.e., group, time, nutrition knowledge). Accordingly, this strong indication of individual differences suggests

that a “one-size-fits-all” nutritional intervention might have limited effectiveness. Instead, in order to achieve more impactful and consistent changes in dietary intake in highly trained adolescent swimmers, interventions may need to be highly personalized, taking into account each individual’s baseline characteristics, responses, and potential underlying physiological or behavioural traits that contribute to this substantial inter-individual variability, as well as utilising a systematic approach that facilitates beneficial behaviour change [50]. Furthermore, when implementing nutrition education programmes for young athletes, nutritionists and coaches should aim to better facilitate changes in behaviour that improve dietary intake for health, growth and development, and performance. These include ensuring that those who may influence adolescent athletes’ dietary intake, such as caregivers and coaching staff, are also supported in understanding best-practice recommendations and practical solutions for young athletes, the creation of accessible resources aimed at both the athlete and their wider network, and providing support on how to practically apply knowledge taught in theory-based sessions.

Acknowledgements

The authors would like to thank the support staff who supported the collection of data, and all participants who participated in the study.

Authors’ contributions

JWN and LAG conceptualisation; JWN, WLF and LAG methodology; JWN, WLF and LAG investigation and data collection; CJR and CC formal analysis; CJR first draft; CJR, NDC and AW second draft and editing; All authors final drafting. All authors approved the final version of the manuscript.

Funding

This study received no external funding.

Data availability

The dataset for this manuscript will be made available upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was granted from the Birmingham City University Health, Education and Life Sciences Faculty Academic Ethics Committee before any research was conducted (Newbury/7596/R(B)/2020/Aug/HELS FAEC).

Consent for publication

All participants provided consent for publication of data.

Competing interests

The authors declare no competing interests.

Received: 19 June 2025 / Accepted: 15 October 2025

Published online: 17 November 2025

References

- Shaw G, Boyd KT, Burke LM, Koivisto A. Nutrition for swimming. *Int J Sport Nutr Exerc Metab*. 2014;24(4):360–72.
- Gudmundsdottir SL. Training schedule and sleep in adolescent swimmers. *Pediatr Exerc Sci*. 2020;32(1):16–22.
- Newbury JW, Foo WL, Cole M, Kelly AL, Chessor RJ, Sparks SA, et al. Nutritional intakes of highly trained adolescent swimmers before, during, and after a national lockdown in the COVID-19 pandemic. *PLoS ONE*. 2022;17(4):e0266238.
- Pollock S, Gaoua N, Johnston MJ, Cooke K, Girard O, Mileva KN. Training regimes and recovery monitoring practices of elite british swimmers. *J Sports Sci Med*. 2019;18(3):577–85.
- Norris SA, Frongillo EA, Black MM, Dong Y, Fall C, Lampl M, et al. Nutrition in adolescent growth and development. *Lancet*. 2022;399(10320):172–84.
- Hannon MP, Close GL, Morton JP. Energy and macronutrient considerations for young athletes. *Strength Cond J*. 2020;42(6):109–19. <https://doi.org/10.1519/SSC.0000000000000570>.
- Ross DA, Hinton R, Melles-Brewer M, Engel D, Zeck W, Fagan L, et al. Adolescent well-being: a definition and conceptual framework. *J Adolesc Health*. 2020;67(4):472.
- Trappe TA, Gastaldelli AM, Jozsi AC, Troup JP. Energy expenditure of swimmers during high volume training. *Med Sci Sports Exerc*. 1997;29(7):950–4.
- Mountjoy M, Armstrong N, Bizzini L, Blimkie C, Evans J, Gerrard D, et al. IOC consensus statement on training the elite child athlete. *Clin J Sport Med*. 2008;18(2):122–3.
- Desbrow B. Youth athlete development and nutrition. *Sports Med*. 2021;51(Suppl 1):3–12.
- Birkenhead KL, Slater G. A review of factors influencing athletes’ food choices. *Sports Med*. 2015;45:1511–22.
- Cole M, Carter JL, Brooks F, Roberts CJ. Caregivers nutrition knowledge and perspectives on the enablers and barriers to nutrition provision for male academy football players. *J Int Soc Sports Nutr*. 2025;22(1):2495879.
- Janiczak A, Alcock R, Forsyth A, Trakman GL. A systematic review of interventions targeting modifiable factors that impact dietary intake in athletes. *Br J Nutr*. 2024;131(2):229–47.
- Spronk I, Kullen C, Burdon C, O’Connor H. Relationship between nutrition knowledge and dietary intake. *Br J Nutr*. 2014;111(10):1713–26.
- Janiczak A, Devlin BL, Forsyth A, Trakman GL. A systematic review update of athletes’ nutrition knowledge and association with dietary intake. *Br J Nutr*. 2022;128(6):1156–69.
- Spronk I, Heaney SE, Prvan T, O’Connor HT. Relationship between general nutrition knowledge and dietary quality in elite athletes. *Int J Sport Nutr Exerc Metab*. 2015;25(3):243–51.
- AlKasasbeh W, Akroush S. Investigating the interrelationships among food habits, sports nutrition knowledge, and perceived barriers to healthy eating: a study of adolescent swimmers. *Front Nutr*. 2024;11:1381801.
- AlKasasbeh WJ, Alawamleh T, Alarahleh WA. Investigating nutrition literacy levels among adolescent swimmers. *Int J Hum Mov Sports Sci*. 2024;12(2):403–13.
- Foo WL, Faghy MA, Sparks A, Newbury JW, Gough LA. The effects of a nutrition education intervention on sports nutrition knowledge during a competitive season in highly trained adolescent swimmers. *Nutrients*. 2021;13(8):2713.
- Webb MC, Beckford SE. Nutritional knowledge and attitudes of adolescent swimmers in Trinidad and Tobago. *J Nutr Metab*. 2014;2014:506434.
- Philippou E, Middleton N, Pistos C, Andreou E, Petrou M. The impact of nutrition education on nutrition knowledge and adherence to the mediterranean diet in adolescent competitive swimmers. *J Sci Med Sport*. 2017;20(4):328–32.
- World Aquatics. Swimming Points. Available at <https://www.worldaquatics.com/swimming/points>. Accessed 27 August 2025.
- Costello N, Deighton K, Dyson J, McKenna J, Jones B. Snap-N-Send: a valid and reliable method for assessing the energy intake of elite adolescent athletes. *Eur J Sport Sci*. 2017;17(8):1044–55. <https://doi.org/10.1080/17461391.2017.1337815>.
- Roberts CJ, Gill ND, Baxter BA, Sims ST. Ecological validation and practical challenges of conducting dietary analysis in athletic individuals using a novel remote food photography method mobile phone application. *J Sci Sport Exerc*. 2024;6(1):90–6.
- Trakman GL, Brown F, Forsyth A, Belski R. Modifications to the nutrition for sport knowledge questionnaire (NSQK) and abridged nutrition for sport knowledge questionnaire (ANSQK). *J Int Soc Sports Nutr*. 2019;16(1):26. <https://doi.org/10.1186/s12970-019-0293-8>.
- Trakman GL, Forsyth A, Hoyer R, Belski R. The nutrition for sport knowledge questionnaire (NSQK): development and validation using classical test theory and rasch analysis. *J Int Soc Sports Nutr*. 2017;14:26. <https://doi.org/10.1186/s12970-017-0182-y>.

27. Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale (NJ): L. Erlbaum Associates; 1988.
28. Burke LM, Hawley JA, Wong SH, Jeukendrup AE. Carbohydrates for training and competition. In: Food, Nutrition and Sports Performance III. 2013;17–27.
29. Newbury JW, Foo WL, Cole M, Kelly AL, Chessor RJ, Sparks SA, et al. Nutritional intakes of highly trained adolescent swimmers before, during, and after a national lockdown in the COVID-19 pandemic. *PLoS ONE*. 2022;17(4):e0266238.
30. Naughton RJ, Drust B, O'Boyle A, Morgans R, Abayomi J, Davies IG, et al. Daily distribution of carbohydrate, protein and fat intake in elite youth academy soccer players over a 7-day training period. *Int J Sport Nutr Exerc Metab*. 2016;26(5):473–80.
31. Fleming JA, Catháin C, Harper LD, Naughton RJ. Dietary intake and daily distribution of carbohydrate, protein and fat in youth tennis players over a 7-day training and competition period. *J Sports Sci Med*. 2021;20(3):413.
32. Costill DL, Flynn MG, Kirwan JP, Houmard JA, Mitchell JB, Thomas R, et al. Effects of repeated days of intensified training on muscle glycogen and swimming performance. *Med Sci Sports Exerc*. 1988;20(3):249–54.
33. Reilly T, Woodbridge V. Effects of moderate dietary manipulations on swim performance and on blood lactate-swimming velocity curves. *Int J Sports Med*. 1999;20(2):93–7.
34. Bestard MA, Rothschild JA, Crocker GH. Effect of low-and high-carbohydrate diets on swimming economy: a crossover study. *J Int Soc Sports Nutr*. 2020;17:1–7.
35. Mujika I, Stellingwerff T, Tipton K. Nutrition and training adaptations in aquatic sports. *Int J Sport Nutr Exerc Metab*. 2014;24(4):414–24.
36. Turner O, Chessor R, Mitchell N. Fuelling gold medals: developing a 'periodised nutrition system' for elite athletes and applying it in practice. *Perform Nutr*. 2025;1(1):4.
37. Jäger R, Kerksick CM, Campbell BI, Cribb PJ, Wells SD, Skwiat TM, et al. International society of sports nutrition position stand: protein and exercise. *J Int Soc Sports Nutr*. 2017;14(1):20.
38. Tipton KD. Efficacy and consequences of very-high-protein diets for athletes and exercisers. *Proc Nutr Soc*. 2011;70(2):205–14.
39. Public Health England. Government dietary recommendations. 2025; Cited 2 Jun 2025. Available from: https://assets.publishing.service.gov.uk/media/5a749fcec5274a44083b82d8/government_dietary_recommendations.pdf.
40. Mancin L, Burke LM, Rollo I. Fibre: the forgotten carbohydrate in sports nutrition recommendations. *Sports Med*. 2025;55:1–17.
41. Czezelewski J, Długolecka B, Czezelewska E, Raczyska B. Intakes of selected nutrients, bone mineralisation and density of adolescent female swimmers over a three-year period. *Biol Sport*. 2013;30(1):17–20.
42. Shoemaker ME, Gillen ZM, McKay BD, Koehler K, Cramer JT. High prevalence of poor iron status among 8-to 16-year-old youth athletes: interactions among biomarkers of iron, dietary intakes, and biological maturity. *J Am Coll Nutr*. 2020;39(2):155–62.
43. Koehler K, Braun H, Achtzehn S, Hildebrand U, Predel HG, Mester J, et al. Iron status in elite young athletes: gender-dependent influences of diet and exercise. *Eur J Appl Physiol*. 2012;112:513–23.
44. Heaney S, O'Connor H, Michael S, Gifford J, Naughton G. Nutrition knowledge in athletes: a systematic review. *Int J Sport Nutr Exerc Metab*. 2011;21(3):248–61.
45. Tam R, Beck KL, Manore MM, Gifford J, Flood VM, O'Connor H. Effectiveness of education interventions designed to improve nutrition knowledge in athletes: a systematic review. *Sports Med*. 2019;49:1769–86.
46. Pelly F, Thurecht R, Slater G. Determinants of food choice in athletes: a systematic scoping review. *Sports Med*. 2022;8(1):77.
47. Stables RG, Kasper AM, Sparks SA, Morton JP, Close GL. An assessment of the validity of the remote food photography method (termed snap-n-send) in experienced and inexperienced sport nutritionists. *Int J Sport Nutr Exerc Metab*. 2021;31(2):125–34.
48. Bassett R, Chapman GE, Beagan BL. Autonomy and control: the co-construction of adolescent food choice. *Appetite*. 2008;50(2–3):325–32.
49. Callis L, Russell M, Hurst H, Hardwicke J, Roberts CJ. Room for improvement in sports nutrition knowledge amongst parents and caregivers of male academy soccer players in the UK: a cross-sectional study. *Nutrients*. 2023;15(20):4331.
50. Bentley MR, Mitchell N, Backhouse SH. Sports nutrition interventions: a systematic review of behavioural strategies used to promote dietary behaviour change in athletes. *Appetite*. 2020;150:104645.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.