A systematic review update of athletes' nutrition knowledge and association with dietary intake

Amy Janiczak*, Brooke L. Devlin, Adrienne Forsyth and Gina Louise Trakman

Department of Dietetics, Nutrition and Sport, LaTrobe University, VIC, Australia

Abstract

Athletes' dietary intakes sometimes do not meet sports nutrition guidelines. Nutrition knowledge (NK) is one factor that may influence dietary intake, but NK measurement tools are often outdated or unvalidated, and results regarding athletes' NK are equivocal. The aims of this systematic review were to update previous systematic reviews by examining athletes' NK and to assess the relationship between athletes' general NK, sport NK and dietary intake. MEDLINE, CINAHL, Scopus, SPORTDiscus, Web of Science and Cochrane were searched for studies published between November 2015 and November 2020 that provided a quantitative measure of NK and described the NK tool used. Twenty-eight studies were included, study quality was assessed using JBI checklists and data on NK score and diet intake was extracted. Eight studies utilised validated, up-to-date NK measurement tools. Mean general and sport NK% scores varied between 40·2% ± 12·4 and 70 % ± 9. Mean protein and carbohydrate consumption was 1·1–3·4 g/kg.bw/d and 2·4–4·6 g/kg.bw/d, respectively. Weak-to-moderate, positive associations were found between NK and positive dietary behaviours. Due to a wide variety of NK measurement tools used, it is difficult to synthesise results to determine overall NK in athletes. Overall, there appears to be a low standard of knowledge. Quality of measurement tools for NK has improved but remains an issue. Future studies should use relevant, current validated NK tools or validate tools in their study population. More research is needed into the relationship between NK and other modifiable factors influencing dietary intake.

Key words: Nutrition knowledge: Athletes: Dietary intake: Sport: Validation: Sports nutrition

Athletes' diets are one of several factors that influence their preparation for, performance in and recovery from competitive sport. The impact of diet on performance can be positive or negative[1], but the margin between winning and losing efforts is also miniscule at times. Nutrition strategies for athletes include preparation for training and competition, as well as providing appropriate nutrients to support recovery[2,3]. Consuming a combination of macronutrients and micronutrients, in the appropriate amounts, at the right time can impact performance in training or competition as well as recovery and immune function[2,4–6].

Previous research indicates that team-sport athletes' dietary practices do not meet sport nutrition recommendations[7]. Failure to meet recommendations can be detrimental to the health of the athlete and overall athletic performance[8]; for example, not consuming appropriate amounts of protein can inhibit new protein synthesis[9] or athletes not meeting energy requirements may experience unplanned weight loss[2], which may impact muscle mass as well as fat mass. It is therefore important to explore possible reasons why athletes might not meet these recommendations. Factors influencing dietary intake include gender, socioeconomic status, taste, convenience and

possibly – the type of sport played, athletic level, nutrition support from sporting club, previous nutrition education and nutrition knowledge (NK)[10,11]. Of these factors, NK has been explored frequently in recent peer-reviewed literature. A higher level of NK in the general population is associated with a greater intake of 'healthy' foods[12], and there is evidence that there is a positive, but weak association between general NK and diet quality in athletes[13,14].

General and sports NK can be assessed using several available tools[15–17], with new tools designed specifically for measuring NK in athletes developed in the past 5 years[18–20]. The current review focuses on tools developed in the past 5 years because it acts as an update to previous literature reviews, with the most recent having been published in 2016[21]. As with all tools, validation must be completed to a sufficient degree to ensure results reflect outcomes being measured. Trakman[21] noted in a previous review that tools for measurement of NK were often not appropriately validated for use. Some tools used to measure NK may have undergone psychometric testing (i.e. have been validated) but may no longer be valid due to outdated information contained within the tool itself[21]. Extensive

modification of items within tools due to translation or changes to accommodate local diet trends may impact validation.

NK is thought to be poor amongst athletes. While there has been no set standard for what constitutes adequate NK, our previous literature review shows that mean percentage scores (i.e. percentage of correct responses) vary widely[21], with twenty-one of the included studies demonstrating scores below 60 %. Several studies have benchmarked the NK of athletes against other groups. A review found the NK of athletes to be equal to or greater than the NK of non-athletes[10]. One study comparing the NK of coaches, athletic trainers and strength and conditioning specialists from the National Collegiate Athletic Association (across all divisions and a wide variety of sports) found 9 % of athletes and 83·1 % of strength and conditioning specialists achieved a NK score >75 %[22].

A systematic review of athletes' NK was published in 2016, providing equivocal results concerning the state of athletes' NK at the time[21]. A large number of studies have been published in this area since 2016. The recent development of current, validated tools has provided researchers with new tools with which to further study athletes' NK[18–20]. This review differs from previous reviews in that it focuses on athlete NK and the relationship with athlete dietary intake[21,23] with a systematic literature review study design[24]. These factors make it worthwhile to revisit a systematic review of athletes' NK to determine if the previous conclusions on studies in this area are still applicable. The aims of this review are to summarise athletes' general and sports NK scores reported in the past 5 years and to examine the quality of the tools used in the assessment of general and sports NK. The secondary aim of this review is to evaluate the association between athletes' NK and dietary intake.

Materials and methods

This systematic review was conducted following the PRISMA guidelines[25] and the protocol registered with PROSPERO (protocol registration ID CRD42020184263).

Search method

One reviewer (AJ) systematically searched the MEDLINE, CINAHL, Scopus, SPORTDiscus, Web of Science and Cochrane databases. For the Medline search, the terms Nutrition Knowledge and Athlete were mapped to the Subject Headings of Nutritional Sciences and Athlete, respectively (see online Supplementary Material for complete search). The following keywords were then added to the search: 'Sport nutrition knowledge' or 'General nutrition knowledge' or 'Nutrition knowledge' and Sport* or Athlete* (online Supplementary Material). References for all included studies were checked for further potential studies to be included in the final review.

Inclusion and exclusion criteria

In order to be included in this review, studies were required to fulfil eligibility criteria as outlined in Table 1. Athletes were defined as any individual participating in an organised sport. Organised sport is defined as physical activity, involving competition and membership with sporting groups. For the purposes of

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Original research (cross-sectional, observational and baseline data from intervention studies)	Reporting general and sport nutrition attitudes, behaviour, habits or intake (without reporting knowledge)
Use standardised questionnaires to measure general and sports NK	Unpublished theses or grey literature
Athletes 17 years of age or older	Athletes under 17 years of age
English language	Qualitative studies
Peer reviewed	
Published between November 2015 and November 2020	
Report a quantitative measure of general and/or sports NK	

this review, adolescents have been excluded due to the potential for age-related confounding factors.

Screening process

Two reviewers (AJ and GT) independently screened all papers for eligibility by reviewing title and abstract, then full-text papers. Disagreements were addressed by discussion, or with a third reviewer (BD) where necessary. Three studies deemed eligible for inclusion through the initial screening process were not included because the full-text article could not be retrieved for data extraction.

Data extraction

A purpose-designed Google spreadsheet was used to extract data from the included studies. One reviewer (AJ) extracted the data from all included studies, and the second reviewer (GT) checked the extracted data for inconsistencies. Any inconsistencies were first discussed to attempt to reach consensus; if consensus could not be reached, the third reviewer (BD) was enlisted to decide. Data extracted with this form included author and date, basic study information (aim, location, setting, study design and recruitment methods), basic questionnaire information (questionnaire name, number of items and subsections included), secondary outcome measurement tool used and format, participant demographics (sample size, age and gender), primary outcome results (mean % score and range of the NK questionnaires) and secondary outcome results (dietary intake measures, either by macronutrient and/or micronutrient intake or food group intake), as well as correlation measures between NK and dietary intake where available.

Quality assessment

The quality of individual studies was assessed using the Joanna Briggs Institute Checklist for Analytical Cross Sectional Studies[26], for assessment of all studies. This assessment tool was chosen as the most appropriate for the study design of studies included in the review. Guidelines for quality assessment were agreed upon among researchers.

Points were allocated for each question within the scale – 'yes' accounting for one point and 'no' or unclear receiving zero points for that question. Validity of the main NK assessment tool

received a score out of two, with a tool requiring a minimum of three types of validity assessment to receive two points, and one or two types of validity assessment to receive one point. Due to differences in total possible points awarded to each paper, the final ranking for each paper was converted to a percentage to allow for comparison (online Supplementary Material).

Analysis

Due to the different NK assessment tools used across the reviewed studies, it was not possible to perform a meta-analysis on these results (see Table 2 for results). Synthesis for this systematic review is narrative – consisting of a descriptive comparison of results across studies. Where applicable, we also summate differences between genders, athletic ability, measurement tools and reported sports.

Results

The initial search provided 1249 articles. After excluding articles that were published prior to November 2015 (*n* 100) and duplicated papers (*n* 312), there were 837 articles included in the abstract and title screening, with seventy articles eligible for full-text screening. Information on the selection process is presented below (Fig. 1). Three studies[27–29] could not be retrieved for full-text screening through university subscription or contact with authors. Full-text screening resulted in twenty-eight studies included in the systematic review, with one additional paper identified through searching reference lists of included studies. One paper was removed during the data extraction process when it was identified as not meeting selection criteria for eligibility.

Study characteristics

The majority of studies (*n* 23) in this review utilised a cross-sectional design. The remaining five studies employed a quasi-experimental design, with education programme interventions. The results of included studies are presented in Table 2. These studies included 3117 participants in total, with eleven[30] to 430[31] participants per study. Nine countries were represented, with ten studies being conducted in the USA and eight studies conducted in Australia (Table 2). Thirty-four sports were represented in these studies, with Australian football, baseball and soccer being the most popular sports reported. Of the Australian studies (*n* 8), seven studies looked at Australian football[11,18,32–36], one paper also looked at soccer[32], while another also included netball and 'other' participants[18]; one Australian-based study looked exclusively at soccer[37].

Seventeen NK tools were used, in full or adapted by researchers, as the measurement tools across the included studies[15–17,22,30,38–49]. Due to the differences between NK measurement tools, it is not feasible to directly compare results from different tools as questions contained within tools can differ greatly. Where possible, we have made comparisons based on participant characteristics across studies that utilised the same tool.

Quality assessment

Raw quality assessment data for individual studies are available in Supplementary Material. Seven studies received 50 % or less for their quality assessment[49–55]. Fifteen studies scored between 51 and 80 %[30–32,34–37,40,56–62]. The remaining six studies scored between 81 and 100 %[11,18,33,63–65], with the highest rating of 100 % going to only one study[11].

Risks of bias within these studies mainly related to lack of validity of the NK tool in testing and generalisability of results. Sixteen of the included studies employed fully validated measurement tools; seven studies utilised partially validated measurement tools. This lack of validation for the measurement tools leaves the results produced by those studies open to measurement bias, making it difficult to ascertain athletes' NK[15]. While validated tools are available, these tools are not necessarily used appropriately by researchers. It is important to note here that validation does not speak to how up to date a tool may be and how current the information within it is.

Only seven of the included studies contained detailed information associated with the athletes' training such as sport played, years playing sport, hours spent training per week or similar aspects related to athletic calibre. For the remaining twenty-one studies, the generalisability of results is difficult to ascertain. Other factors influencing the quality ratings of studies were lack of clear reporting of recruitment methods (*n* 14), response rates (*n* 23) and completion rates (*n* 19) of questionnaires.

Of note, recruitment of participants in many studies was reliant upon convenience sampling and study samples are often small; however, due to the small number of athletes involved in elite sports and heterogeneity of this group, small sample sizes may be representative of the target population.

Ten of the included studies examined correlation between NK and dietary intake; only six of these studies identified possible confounders and implemented a statistical strategy to deal with those confounding factors. This indicates an inappropriate use of statistical analysis within studies, potentially introducing statistical bias and misrepresentation of results.

Questionnaire

General Nutrition Knowledge Questionnaire (1999)

The General Nutrition Knowledge Questionnaire tool by Parmenter & Wardle[16] was used in three studies in this review[57,61,65]. This tool was fully validated in a population of undergraduate students and contains 110 items with four subsections – dietary recommendations, sources of foods/nutrients, choosing everyday foods and diet–disease relationships. Total mean percentage scores for this tool ranged between 47·30 % (SD not available)[57] and 58·4 ± 8·5 %. Mitchell *et al.*[57] reported the scores for the subsections, which showed that the subsection with the lowest score was diet–disease relationships for both the control and experimental groups. The highest scores were in the subsection of sources of foods/nutrients for the control group and dietary recommendations for the experimental group.

Table 2. Data extraction for NK in athletes

Study information (author(s), year, study location)	Sport	Participant information (total number, age, gender)	Questionnaire information	Mean % scores (total, general and sports where available)
Abbey, Wright, & Kirkpatrick 2017[60] USA	American football	n 88 19·6 ± 1·7 (mean ± SD) Male = 88	Torres-McGehee et al.[22] =17 multiple-choice questions topics: macronutrients, micronutrients, supplements, weight management and hydration included three questions regarding nutrition info sources, comfort with sources and perceived adequacy	Mean ± SD TNK = 55·2 ± 16·3 %
Andrews, Wojcik, Boyd, & Bowers 2016[54] USA	Baseball, tennis, track and field, men's soccer, softball	n 123 Age not specified Male = 76, Female = 47	Torres-McGehee et al.[22] 19 item questionnaire 3 demographics 16 – multi-choice on sport nutrition	Mean ± SD TNK = 56·9 ± 14·3 %
Andrews & Itsiopoulos 2016[37] AUS	Soccer	Professional n 29 22 (18–27) Male = 29. Semi-professional n 44 21(18–33) Male = 44	FNKQ[38] Professional – 94 GNK, 29 SNK knowledge of dietary recommendations, sources of nutrients and food and fluid choices Semi-professional – 83 GNK, 26 SNK 7 removed from SNK Added items adapted from Zinn et al.[3] or sport nutrition publication[1]	NK Mean ± SD Professional:Semi-professional GNK = 54·1 ± 13·4:56·8 ± 11·7, SNK = 56·9 ± 15·5:61·3 ± 15·9, TNK = 54·8 ± 13·0:57·9 ± 11·6
Argolo, et al. 2018[63] Brazil	Table tennis	n 17 33 ± 10·8 (mean ± SD) Male = 17	Nascimento et al. & Leite et al.[30,39] Demographics, 14 questions validated NK test (basic nutrition, Brazilian Food Guide Pyramid, Sport nutrition)	Mean (SD) Total = 66·7 (10), Basic nutrition = 97 (9·4), Food pyramid = 17·6 (10), Sports nutrition = 79·4 (21)
Balaravi et al. 2017[40] Malaysia	Not specified	n 50 Median age = 22(IQR = 6) Male = 33 Female = 17	Validated by expert panel for this study 16 questions – knowledge 8 questions – attitude towards supplement/doping relationship	Mean % (SD) < 25 years = 58·75 (13·9) > 25 years = 65·81 (10·3)
Blennerhassett, McNaughton, Cronin, & Sparks 2019[64] UK	Ultra-endurance	n 101 Male = 41·7 ± 8·1, (mean ± SD). Female = 39·0 ± 9·6 (mean ± SD). Male = 74, Female = 27	SNKQ adaptation ULTRA-Q[17] 8 demographic questions & sources of NK 76 questions – nutrients (37), fluid (8), recovery (11), body composition (12), supplements (8)	Mean ± SD Total = 68·3 ± 9·5, Nutrients = 70·8 ± 11·5, Fluid = 58·2 ± 18·6, Recovery = 77·8 ± 15·3, Body composition = 70·1 ± 15·4, Supplements = 51·1 ± 30·6
Coccia, Fernandes, & Altiti 2020[49] USA	Baseball, softball, and swimming	n 50 19·62 ± 1·483 Male = 11, Female = 39	Developed by authors based on Dietary Guidelines of Americans 2010 recommendations five items – regarding fruits and vegetables, dietary fat, dairy and whole grains	n 28 Mean ± SD, % Pre-test:Post-test 3·04 (1·02), 60·8 %: 3·52 (1·12) 70·4 %
Condo, Logman, Kelly, & Carr 2019[36] AUS	Australian football	n 30 24·15 ± 4·1 (mean ± SD) Female = 30	SNKQ[17] 88 questions – general nutrition concepts, fluid, recovery, weight control, supplements	Median (IQR), % General nutrition concepts = 28 (7), 60·8 Fluid = 6 (7), 66·7 Recovery = 4 (3), 57·1 Weight control = 7 (3), 46·7 Supplements = 2 (3), 18·2 Total = 48 (12), 54·5
Devlin, Leveritt, Kingsley, & Belski 2017[32] AUS	Australian football, soccer	n 66 23 ± 4 (mean ± SD) Male = 66	FNKQ[38] 123 questions – dietary recommendations (12), sources of nutrients (69), choosing everyday foods (10), alcohol (3), sports nutrition (29)	Mean % (SD) TNK = 57 (9·7) GNK = 56 (9·7) SNK = 60 (14·5)
Hardy, Kliemann, Evansen, & Brand 2017[65] USA	Not specified	n 194 18–19 - 95 (49 %), 20–21 - 83 (42·8 %), >= 22 - 16 (8·2) Male = 82 Female = 112	GNKQ[16] 4 sections: dietary recommendations, sources of foods/nutrients, choosing everyday foods, and diet–disease relationships gender, age, college cumulative GPA, nutrition courses taken during high school and college, student-athlete status, sports in which they currently participate energy drink questions for people who identified themselves as energy drink consumers	Mean ± SD TNK = 58·4 (8·5)

Table 2. (*Continued*)

Study information (author(s), year, study location)	Sport	Participant information (total number, age, gender)	Questionnaire information	Mean % scores (total, general and sports where available)
Holden et al. 2018[59] USA	Baseball, women's volleyball, women's soccer, track and field, American football	n 80 Age not reported Male = 49 Female = 31	SNKQ[17] 88 total questions Demographic questions – age, gender, GPA, year in school, race Six sections – nutrients, fluid, recovery, weight gain, weight loss and supplements	Mean ± SD TNK = 48 ± 8
Jenner, Devlin, Forsyth, & Belski 2020[33] AUS	Australian football	n 26 24·2 ± 4·2 (mean ± SD) Female = 26	NSKQ[15] 89 questions – weight management (13), macronutrients (30), micronutrients (13), sports nutrition (13), supplements (12), alcohol (8) demographic questions (age, education status and experience in AF)	Mean ± SD Total = 50·6 ± 14, weight management = 57 ± 17, macronutrients = 60 ± 17, micronutrients = 41 ± 22, sports nutrition = 51 ± 19, supplements – = 23 ± 14, alcohol = 70 ± 23
Jenner et al. 2018[34] AUS	Australian football	n 46 24·2 ± 4·0 (mean ± SD) Male = 46	NSKQ[15] 89 questions – weight management (13), macronutrients (30), micronutrients (13), sports nutrition (13), supplements (12), alcohol (8)	Mean % (SD) total = 46 (14·6), weight management = 49 (18·5), macronutrients = 58 (17), micronutrients = 39 (19·2), sports nutrition = 47 (22·3), supplements = 28 (15·8), alcohol = 53 (22·5)
Judge et al. 2016[56] USA	American football	n 100 18–18, 19–26, 20–18, 21–23, 22–12, 23–3 Male = 100	Nichols et al.[43] Demographic questions – age, ethnic group, team position, number of seasons played, previous nutrition education, sources of information knowledge, attitude and behaviour questions – fluid and hydration, primary sources of nutrition information, dietary information, barriers to fluid consumption	Mean % (SD) TNK = 69·4 (11·2)
Lohman, Carr, & Condo 2019[35] AUS	Australian football	n 71 Elite = 25 ± 13 (mean ± SD). Sub-elite = 21 ± 3 (mean ± SD) Male = 37	SNKQ[17] 88 questions – general nutrition concepts (46), fluid (9), recovery (7), weight control (15), supplements (11)	Median (IQR), % elite (n 37): sub-elite (n 34) Total = 45 (11), 51 %; 45 (17), 51 % general nutrition concepts = 27 (8), 59 %: 57 (8), 58 % fluid = 6(8), 67 %:6(6), 67 % recovery = 3 (2), 43 %: 3 (3), 43 % weight control = 7 (4), 47 %: 7 (3), 47 % supplements = 3 (3), 27 %: 2 (4), 18 %
Madrigal, Wilson, & Burnfield 2016[51] USA	American football, track and field, soccer, volleyball, basketball, bowling, gymnastics, rifle, swimming/diving, golf, wrestling	n 196 Mean = 20·1 (SD = 1·2) Male = 145 Female = 51	SNKQ[17] 61 questions – general nutrition (35), hydration (6), weight control (8), recovery (3), supplements (9)	Median (IQR), % Males:Females total (n 119&45) – 29(22–35), 49·5:30(23–36), 49·2 general nutrition (n-131 & 47) = 21(16–23), 60:21(18–24), 60 hydration (n-141 & 51) = 3(2–4), 50:3(2–4), 50 weight control (n 137&51) = 2(1–4), 25:2(1–4), 25 recovery (n 135&51) = 1 (0–2), 33·3:1(1–2), 33·3 supplements (n 140&49) = 2(0–3), 22·2:1(0–3), 11·1
Magee, Gallagher, & McCormack 2016[31] Ireland	Rugby/Gaelic/soccer, sprinting, endurance, Gaelic, hockey, karateka, netball, army officer cadets, cycling, bootcamp, golf	n 430 Age not reported Genders not reported	SNKQ[17] 87 questions – general nutrition (41), fluid (9), recovery (11), weight control (15), supplements (11)	Mean % (SD) total = 52·9 (3·45), general Nutrition Score = 58·5 (4·3), Fluid score = 55·6 (5·6 Recovery score = 45·5 (6·8), Weight control score = 53·3 (5), Supplement score = 27·3 (6·8)
McCrink, McSorley, Grant, McNeilly, & Magee 2020[60] Northern Ireland	Gaelic football	n 24 (for NSKQ results) Median = 23·0 (IQR = 20·0, 27·0) Male = 24	NSKQ[15] 89 questions – weight management (13), macronutrients (30), micronutrients (13), sports nutrition (13), supplements (12), alcohol (8)	Mean % ± SD Total – 40·2 ± 12·4, macronutrients – 46·8 ± 14·5, micronutrients - 41·0 ± 22·3, weight management – 44·6 ± 18·4, supplements – 20·5 ± 16·1, sports nutrition – 30·1 ± 14·9, alcohol - 52·6 ± 21·5
Mitchell et al. 2016[57] USA	Baseball	n 57 Control = 20·03 (Mean) Experimental = 19·83 (Mean) Male = 57	GNKQ[16] 110 questions – dietary recommendations (11), sources of foods/nutrients (69), choosing everyday foods (10), diet–disease relationships (20)	Mean % (SD not available) Control pre: experimental pre overall = 50·67:47·30, dietary recommendations = 55·90:54·82, sources of foods/nutrients = 57·28:51·01, choosing everyday foods = 40·00:50·30, diet–disease = 30·35:28·85

Table 2. (*Continued*)

Study information (author(s), year, study location)	Sport	Participant information (total number, age, gender)	Questionnaire information	Mean % scores (total, general and sports where available)
Murphy & O'Reilly 2020[61] Ireland	Hurling	n 328 elite n 129, sub-elite n 136, 18–21 = 70, 22–27 = 127, 28–32 = 47, 33+= 21, Male = 328	GNKQ[16] 89 sports NK questions – nutrient types (46), recovery (7), fluid (9), weight management (15), supplements (11)	Median, % (IQR) Section 1 - 22, 50 % (18–24)* Section 2 - 5, 62·5 % (4–6) Section 3 - 5, 45·5 % (4–7) Section 4 - 1, 25 % (1–2) Section 5 - 7, 58·3 % (6–8) Section 6 - 3, 27·3 % (2–4) Total - 42, 48·8 % (37–47)
Nascimento et al. 2016[30] Brazil	Not specified	n 11 (adult participants) 23·7 (SE = 0·53) Male = 11	Goncalves et al. & Zawila et al.[42,47] 14 questions – basic nutrition (3), Brazilian food pyramid (1), sports nutrition (10)	Mean % (SD) total = 70 (9), Basic nutrition = 89·7 (23), Food pyramid = 28·4 (26), Sports nutrition = 84·5 (11)
Renard, Kelly, Cheilleachair, & Cathain 2020[62] Ireland	Football & camogie	n 328 18–24, n 215 25–30, n 83 31+, n 30 Female = 328	ANSKQ[15] 37 questions – general nutrition (17) (energy density, role and sources of macro and micronutrients and alcohol), sports nutrition (20) (macronutrient & fluid requirements, weight loss and gain strategies and supplementation)	Mean % (SD) TNK: 46·0 (11·8), GNK: 58·2 (15·6), SNK: 40·4 (13·0), Football TNK: 46·0 (12·0), GNK: 58·2 (15·0), SNK: 40·4 (13·7), Camogie TNK: 46·3 (11·3), GNK: 59·1 (13·6) SNK: 40·4 (11·6)
Rossi et al. 2017[58] USA	Baseball	n 15 19·3 (1·0) Male = 15	Sport Nutrition Questionnaire[45] 46 questions – demographics, dietary behaviours, hydration, weight control, dietary supplements, general nutrition, sports nutrition, protein, strategies for training, food choices	Mean % (SD) 56·7 (SD = ±11·4)
Saribay & Kirbas 2019[52] Turkey	Track and field, soccer, basketball, handball, other	n 150 17 years n 112, 18+ n 38, Gender split not available	Nutrition Knowledge Scale for Adolescents[44] 38 questions –adequate and balanced diet (9), food items (21), nutrient related health problems (8)	Mean ± SD 17 years = 53·6 ± 12·7 18+ years = 51·4 ± 13·1
Simpson, Gemming, Baker, & Braakhuis 2017[53] New Zealand	Hockey	n 17 19 ± 0·7 (mean ± SD) Male = 17	Questionnaire of Nutritional Knowledge[17,41] 47 questions – basic nutritional knowledge (11), behavioural effects of food availability and choice (8), sports NK and practices (28) + demographics	Mean ± SD total = 54·7 ± 14·3 general NK = 58·8 ± 21·8, hydration = 61·4 ± 20·5, body composition = 29·4 ± 18·19, dietary supplements = 44·7 ± 26·01, recovery nutrition = 70·7 ± 14·6, event nutrition = 43·08 ± 14·62, training nutrition = 60·8 ± 29·44
Trakman, Forsyth, Hoye, & Belski 2018[18] AUS	Australian football, netball, other	n 181 17–25 = 85, 26–35 = 66, >= 36 = 26 Male = 69 Female = 108	A-NSKQ[15] 37 questions – general nutrition (17) (energy density, role and sources of macro and micronutrients and alcohol), sports nutrition (20) (macronutrient & fluid requirements, weight loss and gain strategies supplementation)	Mean ± SD TNK = 47 ± 12 GNK = 59 (18) SNK = 35 (18)
Trakman et al. 2018[11] AUS	Australian football	n 140 Elite AF: Nonelite AF 17–25 – 29:26, 26–35 – 17:20, 36+–0:7	NSKQ[15] 89 questions – weight management (12), macronutrients (30), micronutrients (13), sports nutrition (13) (hydration, nutrition before, during and after), supplementation (13), alcohol (8)	Mean ± SD (%), Range (%) Elite AF: Nonelite AF Total = 45·5+/–14·7, 10–69:50·9+/–11·0, 28–72. Weight management = 48·3+/–18·0, 15–77:56·7+/–17·8, 15–92. Macronutrients = 57·0+/–17·3, 13–83:58·9+/–15·3, 27–97. Micronutrients = 38·8+/–18·8, 15–70:49·9+/–16·3, 15–85. Sports nutrition = 46·5+/–22·2, 8–69:46·0+/–14·7, 8–70. Supplements = 27·7+/–16·6, 0–67:34·3+/–19·1, 0–67. Alcohol = 52·4+/–22·9, 0–88:70·5+/–17·00, 25–75
Werner, Guadagni, & Pivarnik 2020[55] USA	Women's rowing, field hockey, basketball, soccer, golf, men's football, basketball, ice hockey	n 125 Age not provided Male = 55, Female = 70	General and Sport Nutrition Knowledge Questionnaire[48] 62 questions – general nutrition (29) and sport nutrition (33)	Mean % (SD) TNK – 57·5 (18·6) GNK – 57·2 (19·8) SNK – 58·5 (19·4)

n, number of participants; SD, standard deviation; IQR, interquartile range; TNK, Total NK; GNK, General NK; SNK, Sports NK; AF, Australian football; FNKQ, Food and Nutrition Knowledge Questionnaire; SNKQ, Sports Nutrition Knowledge Questionnaire; GNKQ, General Nutrition Knowledge Questionnaire; NSKQ, Nutrition for Sport Knowledge Questionnaire; ANSKQ, Abridged Nutrition for Sport Knowledge Questionnaire.
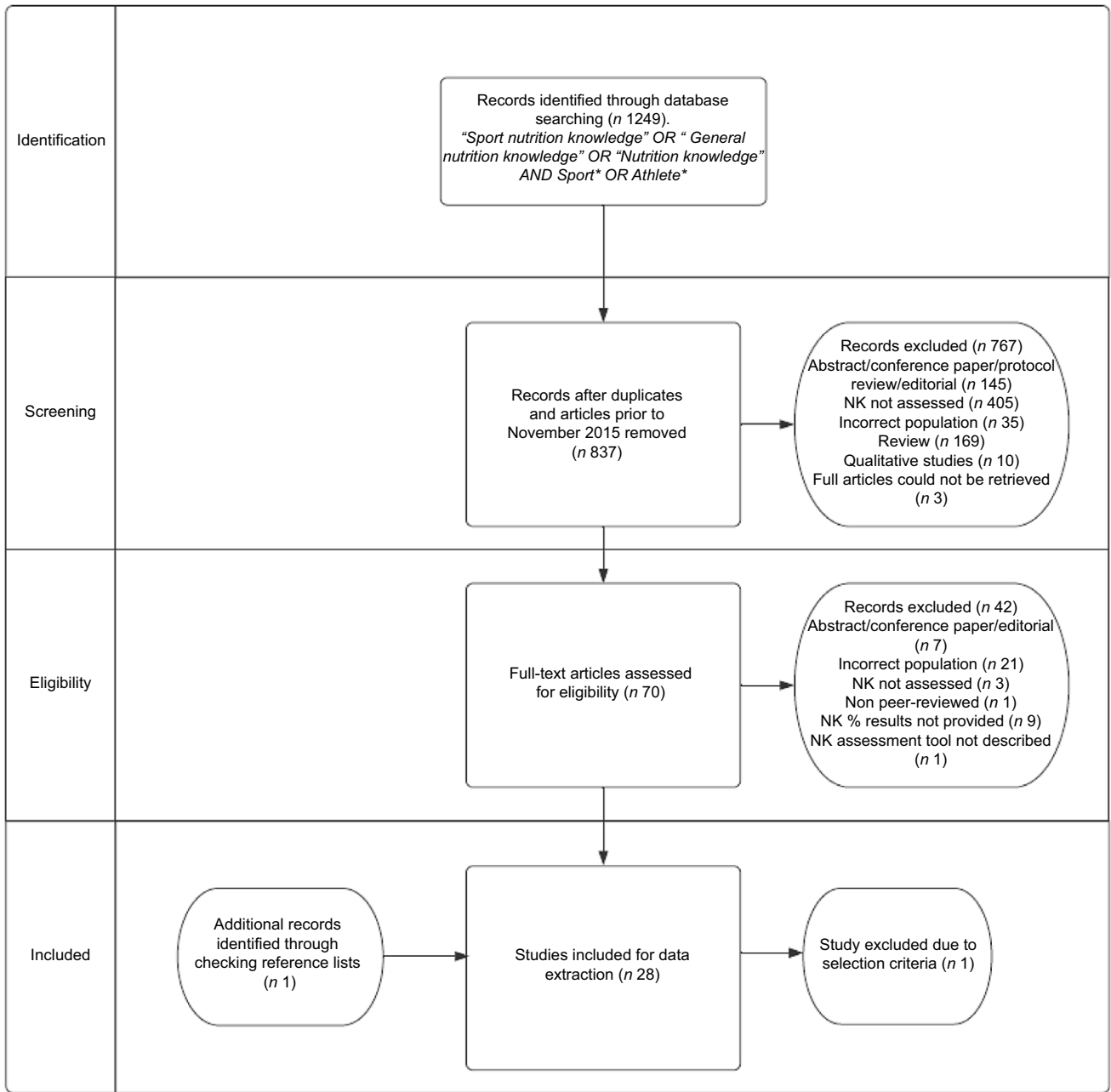* Reported as 18–14 in original paper, corrected values reported here.

Fig. 1. Selection process flow chart. NK, nutrition knowledge; *n*, number of studies.

Sports Nutrition Knowledge Questionnaire (2005)

Questionnaire use and validation. Six of the included studies employed the Sports Nutrition Knowledge Questionnaire (SNKQ)[17], which was fully validated for content, construct and test–retest validity in nutrition and business university students. One of these studies adapted and validated the SNKQ for use[64], and this will be described below (ULTRA-Q Adaptation). Studies were in Australian football, baseball, volleyball, soccer, track and field, American football and a variety of collegiate sports[31,35,36,51,59]. The SNKQ has a maximum eighty-eight items – subsections include general nutrition concepts, fluid, recovery, weight control and supplements. Three studies used this tool in full[35,36,59]. The remaining two studies used eighty-seven and sixty-one items; the removal or alteration to items allowed for concepts to be updated to more recent recommendations, while maintaining the original subsection topics of the SNKQ[31,51]. Madrigal *et al.* and Magee *et al.* did not undertake or discuss tool validation after tool modification.

Results across studies and sub-section scores. Total percentage scores for studies using the SNKQ varied between 48 ± 8 % and 54·7 ± 14·3 %. Those studies that included results of sub-sections showed that participants often scored lowest in

supplement sections[31,35,36,51]. Performance varied across studies, with highest scores achieved in different subsections including nutrients[51], fluids[35,36] and recovery[53,64].

Comparisons across sports and athletic calibre. Due to the use of adapted or modified tools, the results of three of these studies could not be compared against those of other studies[31,51,64]. The three studies able to be compared here looked at various sports: women's Australian Rules football[36], baseball, women's volleyball, women's soccer, track and field, football[59] and elite and sub elite Australian football[35]. The three sports with highest scores for total NK were women's Australian Rules football (Median = 60·8 %), and elite and sub-elite Australian Football (Median = 51 % and 51 %). The three sports with the lowest mean scores were American football (46 ± 7 %), track and field (48 ± 7 %) and women's soccer (49 ± 1 %).

ULTRA-Q adaptation. The Blennerhassett *et al.*[64] study investigated NK in ultra-endurance athletes. The tool used was a validated (for content validity and test–retest reliability) adaptation of the SNKQ, containing seventy-six items in the sections of nutrients (37), fluid (8), recovery (11), body composition (12) and supplements (8). Ultra-endurance athletes within this study had a total mean score of 68·3 ± 9·5 %. Results from this study are unable to be compared with studies utilising the SNKQ due to possible differences in the measurement tool caused by adaptation.

Torres-McGehee et al. (2012)

Questionnaire use and validation. Two studies[50,54] utilised adaptations of the partially validated (for construct validity) Torres-McGehee *et al.* tool[22], using either seventeen items or nineteen items within the questionnaire. Studies were in American football, baseball, tennis, track and field, soccer and softball. Andrews *et al.*[54] completed content validity testing and internal consistency testing using Cronbach's α, making the tool partially validated. However, Abbey *et al.*[50] did not undertake any validation.

Results across studies and sub-section scores. The total mean nutrition scores were 55·2 ± 16·6 %[50] and 56·9 % sd = 14·3[54]. Scores across sports have been compared; results show men's soccer players achieved the highest score 59·4± %, followed by track and field (57·4 ± 11·3 %), tennis (56·7 ± 15·8 %), American football (55·2 ± 16·3 %), baseball (55·2 ± 15·0 %) and softball (54·4 ± 15·4 %). Abbey *et al.*[50] found that <50 % of participants correctly answered questions relating to athlete macronutrient balance, micronutrients, ergogenic aids, body composition and muscle mass, and >75 % of participants correctly answered items on fuel for exercise, creatine supplementation, rehydration and electrolyte loss[50].

No studies using this tool benchmarked athletic groups against other cohorts or compared results across athletic calibres.

Food and Nutrition Knowledge Questionnaire (2015). Two studies[32,37] utilised the Devlin & Belski tool[38], which was originally developed as an amalgamation of the General Nutrition

Knowledge Questionnaire tool and a sports specific knowledge assessment tool by Shifflet *et al.*[16,38,46]. Studies were in soccer and Australian football. This tool contains 123 items under the subsections of dietary recommendations, sources of nutrients, choosing everyday foods, alcohol and sports nutrition. This tool was not validated by Devlin and Belski[38] in the original creation of this tool, nor was this validated by Devlin *et al.*[32], although Andrews and Itsiopoulos[37] completed content validity testing on their modified version. Changes were made to the tool by Andrews and Itsiopoulos[37] when assessing the NK of semi-professional players, though the full tool was used to assess professional players in their study. The Andrews and Itsiopoulos[37] study found that semi-professional players had higher mean scores for all areas of the questionnaire than their professional counterparts – general NK (56·8 ± 11·7 % and 54·1 ± 13·4 %, respectively), sport NK (61·3 ± 15·9 % and 56·9 ± 15·5 %, respectively) and total score (57·9 ± 11·6 % and 54·8 ± 13·0 %, respectively). Devlin *et al.*[32] reported a total NK score of 57 ± 9·7 %, General Nutrition Knowledge Questionnaire mean percentage score of 56 ± 9·7 % and sport NK score of 60 ± 14·5 %.

Nutrition for Sports Nutrition Knowledge Questionnaire (2017). Six studies[11,18,33,34,60,62] employed the Nutrition for Sport Knowledge Questionnaire (NSKQ) or A-NSKQ[15,18,66]. The NSKQ has eighty-seven to eighty-nine questions, broken into six subsections – weight management, macronutrients, micronutrients, sports nutrition, supplements and alcohol. Two studies utilised the abridged form of this tool, A-NSKQ[18,62], while the remaining four used the entire tool[11,33,34,60]. The entire NSKQ tool was validated for content validity, construct validity and testing of item behaviour. The A-NSKQ[15,18,66] was also validated for construct validity, internal validity and test–retest reliability and contains thirty-five or thirty-seven items in two subsections – general NK and sports NK.

The total mean percentage scores for the NSKQ ranged between 40·2 ± 12·4 % and 50·9 ± 11 %, while the A-NSKQ means were 47 ± 12 % and 46 ± 11·8 %. The studies that used the entire tool provided details of subsection results. The lowest scores across all studies were in the subsection of supplements, ranging between 20·5 ± 16·1 % and 34·3 ± 19·1 %. Female Australian football players (70 ± 23 %), Irish Gaelic football players (52·6 ± 21·5 %) and non-elite Australian Football players (70·5 ± 17 %) scored the highest results in the subsection of alcohol[11,33,60]. Elite and professional Australian Football players scored highest under the subsection of macronutrients (57 ± 17·3 % and 58·9 ± 15·3 %, respectively)[11,34]. The studies using the shortened tool showed that athletes across the sports of Female Irish football and camogie players (GNK = 58·2 ± 15·6 %, SNK = 40·4 ± 13·0 %), Australian football players, netball players and 'other' athletes (GNK = 59 ± 18 %, SNK = 35 ± 18 %) scored higher in the general NK section of the questionnaire than the sports NK section[18,62]. The results of the NSKQ and A-NSKQ cannot be compared due to the differences between the two tools.

The remaining studies used tools not used in any other study included in this review. Argolo *et al.*[63] utilised an amalgamation of two questionnaires[30,39] resulting in a fourteen-item tool

containing sections on basic nutrition (3), Brazilian Food Guide pyramid (1) and sport nutrition (10), which was tested for discriminative validity, internal consistency and construct validity. For the table tennis players, the total percentage mean score was 66·7 ± 10 %. The area with the highest score was basic nutrition (97 ± 9·4 %). The area of lowest score was the food pyramid based on the Brazilian food pyramid (79·4 ± 21 %).

Balaravi *et al.*[40] generated a twenty-four-item tool for use in their paper containing sections on supplement NK (16) and attitudes towards supplement doping (8), which was partially validated by testing for content validity and internal consistency in Malaysian athlete populations. For the purposes of this study, the results of the supplement NK section of the tool will be reported. The results from this study showed that elite Malaysian athletes from various sports mean percentage scores of 58·75 % for athletes <25 years of age and 65·81 % for athletes over 25 years of age.

Coccia *et al.*[49] developed a five-item multiple choice tool for use in their paper that assessed NK related to fruits, vegetables, dietary fat, dairy and whole grains, which was not validated for use. The mean percentage score of the baseball, softball and swimming athletes was 60·8 ± 20·4 %.

Judge *et al.*[56] assessed NK in American football players using the seventeen-item tool developed by Nichols *et al.* containing items focused on hydration, which was tested for content validity in college athletes[43]. The total mean percentage score from this study was 69·4 ± 11·2 %.

Nascimento *et al.*[30] used a fourteen-question tool that was an amalgamation of two tools previously used[42,47] containing sections on basic nutrition (3), Brazilian food pyramid (1) and sports nutrition (10). This study looked at athletes in various sports. Nascimento *et al.*[39] tested the resulting tool for validity, using construct validity test and item discrimination to achieve partial validation. Adults in this study had a mean percentage score of 70 ± 9 % for the overall questionnaire. Participants scored highest in the subsection of basic nutrition, 89·7 ± 23 % and lowest in the subsection on the Brazilian food pyramid, 28·4 ± 26 %.

Rossi *et al.*'s[58] study of baseball players utilised a partially validated, forty-six-item tool, which was an adaptation of the Sports Nutrition Questionnaire[45] containing sections on hydration, weight control, dietary supplements, general nutrition, sports nutrition, protein, strategies for training and food choices. The total mean percentage score for this study was 56·7 ± 11·4 %.

Saribay & Kirbas's[52] adolescent athlete study used the thirty-eight-item tool developed by Oz *et al.*[44] (Nutrition Knowledge Scale for Adolescents), which was tested for test–retest reliability and internal consistency; this tool contains subsections on adequate and balanced diet (9), food items (21) and nutrient-related health problems (8). Participants 18 years and older had a mean percentage score of 51·4 ± 13·1 %, and participants 17 years of age had a mean percentage score of 53·6 ± 12·7 %. No statistically significant difference was reported between age groups included in this study (14 years to 18 years and over).

Simpson, Gemming, Baker, & Braakhuis[52] employed an unvalidated, forty-seven-item tool adapted from Burkhart[41] and Zinn *et al.*[17] (Questionnaire of Nutritional Knowledge), which contains sections on basic nutritional knowledge (11),

behavioural effects of food availability and choice (8) and sports NK and practices (28). The elite athletes in this study had an overall mean percentage score of 54·7 ± 14·3 %. Participants scored highest on questions related to recovery nutrition (70·7 ± 14·6 %) and lowest on questions related to body composition (29·4 ± 18·2 %).

Werner, Guadagni, and Pivarnik's[55] study of Division I collegiate athletes in the USA used the fully validated General and Sport Nutrition Knowledge Questionnaire, sixty-two-item tool first developed by Callela *et al.*[48], which included subsections on general (29) and sport nutrition (33). The total mean percentage score was 57·5 ± 18·6 %.

Dietary intake

Twelve studies included data on dietary intake. Dietary intake was measured using a variety of methods: FFQ, food diaries, 24-h food recalls and 4-d semi-quantitative food records. Macronutrients were reported in various ways: grams per day, grams per kilogram of bodyweight per day, or percent of total energy intake. Comparisons between studies are limited due to varying methods of collecting and reporting diet intake data. Those studies including amounts of protein and carbohydrate measured in grams per kilogram of body weight per day[32,34–37,60,63] had results varying between 1·1 g/kg.bw/d and 3·4 g/kg.bw/d of protein and 2·4 g/kg.bw/d and 4·6 g/kg.bw/d for carbohydrate. Daily carbohydrate intake recommendations for sport nutrition vary between 3 and 12 g/kg.bw/d, while daily protein intake recommendations for sport nutrition are between 1·2 and 2·0 g/kg.bw/d[2]. Mean fibre values across studies (*n* 7) varied between 15 g and 45·8 g per d[34–37,50,60,63]. Studies reporting fat intake in grams per kilogram of body weight per day produced results between 0·9 g/kg.bw/d and 1·6 g/kg.bw/d[32,34,35,60]. Saturated fat intake was reported as between 9·4 % and 13·4 % of total energy intake[35,36,60,63]. A summary of dietary intake data is provided in Supplementary Material.

A small number (*n* 5) of studies reported various micronutrient intakes. Na intakes ranged between 2063·3 mg and 9404·3 mg per d[36,50,60,63]. Reported Ca intakes ranged from 648 mg to 1080·9 mg per d[34,36,60,63]. Potassium intakes fell between 3109 mg and 6298·1 mg per d[36,50,60]. Zinc intakes were between 8·8 mg and 11·7 mg per d[36,60,63].

Correlation between dietary intake and nutrition knowledge

Studies that examined correlations between dietary intake and NK (*n* 6) reported multiple associations, which are outlined in Supplementary Material. Andrews & Itsiopoulos[37] noted moderate positive correlations between sports NK and mean energy intake ($r = 0.31$, $P = 0.04$) in Australian soccer players, as well as between sports NK and carbohydrate intake ($r = 0.35$, $P = 0.02$). Argolo *et al.*[63] found a negative correlation between Brazilian adult table tennis players' total NK and their Na intake ($r = -485$, $P < 0.05$). Australian Football and soccer players displayed a weak, statistically significant, positive correlation between sport NK and both total energy intake and total carbohydrate intake ($r^2 = 0.046$, $P = 0.014$ and $r^2 = 0.043$, $P = 0.039$, respectively);

a medium-large, statistically significant, negative correlation was also found in elite Australian football players between general and sports NK score and total protein intake ($r^2 = 0.244$, $P = 0.026$ and $r^2 = 0.382$, $P = 0.016$, respectively)[32]. A significant, negative correlation between NK scores in dietary recommendations and higher intake of caffeinated energy drinks was reported ($r = 0.48$, $P < 0.001$) in American student-athletes[65]. A study of Australian football players[34] demonstrated a moderate, positive association between NK scores and meeting estimated energy requirements ($r = 0.325$, $P = 0.031$), as well as NK scores being positively associated with protein, fibre and Ca intakes ($r = 0.348$, $P = 0.021$; $r = 0.510$, $P = 0.001$ and $r = 0.428$, $P = 0.004$, respectively). Murphy at al.'s[61] study of Irish hurlers found a weak to moderate positive association between NK and the Australian Recommended Food Score (a diet quality score validated for use in athlete populations) ($r = 0.3$, $P = 0.007$), with sub-elite players having a weak positive association ($r = 0.26$, $P = 0.002$) and elite players have a moderate positive association ($r = 0.35$, $P = 0.006$).

Discussion

NK amongst athletes is a popular topic, with twenty-eight studies published over the past 5 years included in this review. Thirteen of these included studies have also explored the dietary intake of athletes, and six studies reported correlations between NK and dietary intake. This review includes 3117 participants from nine countries, participating in thirty-four different sports.

According to evidence presented here, many athletes do not meet minimum NK requirements to 'pass' a NK test (based on the convention of 50 %, n 8), suggesting that they are unfamiliar with general and sports-specific dietary recommendations. Of the 10 studies that set a 'pass' mark for adequate NK, three studies using the NSKQ[15] for NK measurement achieved an 'average' or 'medium' score (non-elite AF players −50·9 ± 11 %, female AF players – 50·6 ± 14 %, variety of USA sports – 57·5 ± 18·6 %)[11,33,55]. The remaining studies had poor or inadequate levels of NK[11,18,34,50,54,59,60,62]. Calculation of an overall mean score is not possible due to the use of different tools. Studies which had cut offs for 'pass' showed that athletes did not achieve passing marks. For other studies, mean percentage scores ranged between 40·2 % and 70 %. Because these were not benchmarked, it is difficult to say if these results are poor or not. These percentages seem low based on face value. Prior systematic reviews had a wider range of scores, with a low of 38·8 % and a high of 83·7 % in a 2016 systematic review[21] and scores between 34 and 71 % in a 2011 review[10]. This wide variety of potential scores may be related to the tools used to measure NK or the population in which NK is being tested. These results may indicate potential knowledge gaps in athletes that will enable athletic support staff to establish relevant nutrition education programs for athletes. It may be possible to use NK assessment tools to measure knowledge before and after the intervention to assess if the education program used was beneficial for the athletes.

Athletes' poor NK could be due to a number of factors. Andrews et al.[54] suggest that the poor NK scores of collegiate athletes within their study may be due to a lack of emphasis on the importance of nutrition for athletic performance by coaches and trainers. A previous study of athletes, coaches, strength and conditioning specialists and trainers found that only 35·9 % of coaches, 9 % of athletes, 71·4 % of trainers and 83·1 % of strength and conditioning specialists had adequate NK[22], suggesting that coaches are not best placed to provide nutrition information to athletes and this task should be left to a team dietitian. Studies have reported mixed findings in relation to the association between having been given advice by a dietitian and NK, with researchers noting that a lack of an association may be because advice provided to athletes by team dietitians focuses more on practical food choice recommendations rather than the types of information assessed using NK tools[32,37].

As the recommended intake of protein and carbohydrate is dependent upon the type of sport and training the athlete is participating in, it is only possible to comment on these intakes when they either do not meet or exceed any recommended intakes. As such, it appears that athletes are below or meeting the requirements for carbohydrate intake for light intensity activities, when compared with current sport nutrition recommendations[2]. The current sport nutrition recommendations for protein intake range between 1·2 and 2·0 g/kg.bw/d[2]. However, the reported intake for protein indicates that some athletes are exceeding this range by 70 %, with a maximum mean intake of 3·4 g/kg.bw/d. A review examining protein intake in soccer players found that only two of the sixteen studies had participants with protein intake exceeding current sport nutrition guidelines (2·3 g/kg.bw/d), and in one study participants did not meet the recommendations (1·0 g/kg.bw/d)[67]. Burke et al.'s 2006[67] review examined carbohydrate intake in soccer players indicated all soccer players included with the sixteen studies being reviewed consumed carbohydrate within the range for current carbohydrate recommendations (4·2–8·3 g/kg.bw/d). However, a 2019 review[68] found a heterogeneous array of results for carbohydrate intake in soccer players (both junior and senior), with results between 2·9 g/kg.bw/d and 12·9 g/kg.bw/d, with senior players displaying a lower maximum carbohydrate intake than junior players (5·9 g/kg.bw/d and 12·9 g/kg.bw/d, respectively). Results of the current review indicate the athletes in the included studies consumed a much lower range of carbohydrate intake (2·4–4·6 g/kg.bw/d). The wider variety of sports included in the current studies should provide for greater variation in carbohydrate consumption due to differences in dietary requirements between sports. However, the smaller range of results may indicate a poor understanding of the benefit of carbohydrate consumption within the athletes included in the study or may be reflective of the popularity of low-carbohydrate diets in athletes in recent years.

The correlation between NK and dietary intake reported in this review demonstrates that those athletes with a higher level of NK are more likely to apply that knowledge to their dietary intake in a positive fashion. This includes moderate positive correlations between NK and other factors, including mean energy intake, carbohydrate intake, fibre, and Ca intakes, and negative correlations between NK and factors such as Na intake and energy drink intake. The relationship between NK and protein was examined in two studies[32,34] and found to be both

British Journal of Nutrition

positively correlated in professional Australian football players ($r = 0.348$, $P = 0.021$) and negatively correlated in elite Australian football players ($r^2 = 0.244$, $P = 0.026$ and $r^2 = 0.382$, $P = 0.016$, respectively). Spronk *et al.*'s[23] systematic review found that higher NK in the general population was associated with greater intake of fruits and vegetables, cereals or fish, fibre, Ca and some core food groups, along with lower intake of fat and sweetened beverages, which could prove beneficial as small differences can be important in elite sports. This confirms that modifying NK is worthwhile when aiming to modify dietary intake. However, the difference in correlation between NK and protein intake suggests that further research is required to investigate this. Athlete protein requirements differ in relation to athlete goals, for instance increased protein intake in athletes wanting to increase muscle mass or those losing weight to minimise muscle loss. In these cases, it is possible that the high protein intake is impacted by an overall restriction of energy (including protein) to maintain lean physique; if protein intake is expressed as %E intake, a decrease in protein intake could reflect an appropriate increase in carbohydrate intake.

While NK has been found to have a weak, positive correlation with dietary intake in the general population[23], NK is not the only factor that could potentially impact dietary intake. Birkenhead and Slater's review[13] placed these factors into the groups of 'physiological and biological', 'lifestyle, beliefs and knowledge', psychological, social and economic. To understand how a nutrition/dietetics professional may impact these factors, they have been classified into modifiable, semi-modifiable and non-modifiable factors[69]. No previous studies have examined relationships between the factors that are modifiable by nutrition/dietetic professionals (hedonic hunger, macronutrient balance, NK and body image and weight control) and dietary intake in athletes. A recent qualitative study of factors influencing dietary intake of professional Australian football players found four main categories of factors body composition assessment and goals, seasonal changes (preseason and competitive season), interpersonal factors related to peers, family and mood and NK and support[70]. These factors closely relate to the factors of body image and weight control, macronutrient balance, hedonic hunger and NK[71]. Body composition assessment and goals are closely linked with body image and weight control, seasonal changes are related to alteration of macronutrient balance to achieve goals, the influence of peers and family is related to the availability of food and hedonic hunger and NK is a constant. This similarity between players' understanding of influences on their dietary intake and factors that nutrition/dietetic professionals can influence the need to investigate these factors further.

Previous systematic reviews related to athletes' NK have found that studies are flawed with inadequate statistical reporting, use of tools that are unvalidated[21] and a lack of benchmarking[10], as well as use of tools that are outdated. The included studies in this review still exhibit a lack of complete validation with twelve studies not using fully validated tools for measuring NK; five studies used unvalidated tools[31,48–50,52] and seven studies used partially validated tools[30,37,40,52,54,56–58]. Studies may fail to use appropriately validated tools because the methods of proving validity for a measurement tool can be time consuming

and difficult to complete. Of note, where studies did use validated tools (n 16), eight studies utilised tools that were more than 15 years old[16,17]. Due to the changes in practice and understanding around athlete nutrition within the past 15 years, it is unlikely that older tools reflect current recommendations. The questionnaires used in studies[11,18,33,34,52,55,60,62] that utilised newer tools included the NSKQ (n 4)[15], the A-NSKQ (n 2)[18], The General and Sport Nutrition Knowledge Questionnaire (n 1) and an amalgamation of two tools that were validated for the study (n 1)[30,39]. This selection indicates that there are a variety of tools available; it should be noted that this is not an exhaustive list of potential validated NK measurement tools for use. It is recommended that when selecting NK measurement tools, a tool that is validated within the research target population would be best or validation within the research target population should be carried out. In studies published since 2020, new, validated tools may not have been used extensively to date due to a possible delay in conducting studies (due to the COVID-19 pandemic) and publishing relevant results.

A recent systematic review by Capling *et al.*[72] determined that there is substantial variability in dietary assessment methods in athletes. A variety of dietary assessment methods were used within the included studies, including FFQ (n 2), food record (n 1), 24-h food recall (n 1), 24-h dietary assessment tool (n 2), multi-pass 24-h food recalls (n 2), 3-day food diaries (n 2) and a 7-day food diary (n 1). While the dietary assessment methods used within these studies are validated and considered appropriate for use within the general population, there are some athlete-specific factors that these dietary assessment methods may not take into consideration. Because this is an emerging area of study, the validity of dietary assessment tools has been accepted as complete if it is a tool that has been validated for use within the general population.

There have been a number of reviews within this space. Spronk *et al.*'s 2014 review examined NK and dietary intake of community populations and athletes, with a larger focus on community population data[23]. Trakman *et al.*'s 2016 review examined the NK of athletes and coaches emphasising the knowledge gaps within these populations, without examining the dietary intake of athletes in relation to dietary intake[21]. A recent narrative review examines NK of USA collegiate athletes and how sports dietitians impact NK and behaviours in those athletes, excluding athletes outside of USA collegiate sport[24]. Heaney *et al.*'s 2011 review combined NK and dietary intake in athletes; however, there has been a wide variety of research published between 2011 and 2020 requiring evaluation in this space[10]. It can be seen from the evidence here that an updated review of this area was required which examined the relationship between NK and dietary intake in athletes specifically.

Limitations

A limitation of this paper is the quality of the studies included in this review. The majority of studies included in this review were cross-sectional studies, or quasi-experimental studies, with many studies having small participant groups without mentioning power calculations, which may impact the generalisability of

the studies to the wider target populations. Some of the tools used to assess NK are also limiting. Tools were not designed for assessment of athlete populations[16,44] were more than 10 years old and likely out of date (i.e. not reflective of current nutrition recommendations)[16,17,42,43,45–47], or have not been fully validated[30,32,37,40,50–54,56–58]. Therefore, results must be interpreted with caution. A wide range of tools used to assess NK made comparison of results difficult between studies; therefore, a meta-analysis was not possible for this review. NK scores measured with tools that do not provide ratings or pass values have not been benchmarked against other population groups (e.g. nutrition experts or community populations), which provides results without context within the larger NK landscape. Dietary intake results are also heterogeneous, making comparisons difficult across all applicable studies. This review has examined the influence of NK on dietary intake, but other influences on dietary intake have not been investigated here.

A large portion of the included studies were conducted in American and European populations across a wide range of sports. All controls or comparators within the included studies were athletes. It should be noted that inadequate descriptions of sporting levels or calibres make comparing these results between studies problematic, as these descriptions may be different between countries and sports. No studies compared the NK of athletes to community populations.

Publication bias is possible as grey literature was not examined, and three studies could not be retrieved to be screened. There is also a possibility that studies in this field have not been published due to negative or inconclusive results. This review was limited to studies published in the English language and thus may have excluded some studies on the basis on language or region. This form of bias is not often an issue within this field, due to the smaller scale studies including relatively small sample sizes.

Conclusion

This review suggests that athletes have poor general and sports NK and often do not meet nutrition recommendations. However, inconsistent validation of tools used in these studies mean that these results must be interpreted with caution. NK and dietary intake were weakly associated in athletes. There are flaws in the measurement of NK, due to lack of validation. Newly created NK assessment tools are lending greater reliability to the results produced. It is necessary for future research to examine a population of athletes, across varying sporting levels, types, and regions, investigating NK and its correlation with dietary intake. It would be beneficial to also benchmark athlete general and sport knowledge and dietary intake against that of community populations. Finally, future studies should consider undertaking a holistic investigation of modifiable factors influencing athletes' dietary intake by looking at NK in combination with other modifiable factors that may impact dietary intake.

Acknowledgements

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114521004311

References

1. Devrim-Lanpir A, Hill L & Knechtle B (2021) Efficacy of popular diets applied by endurance athletes on sports performance: beneficial or detrimental? A narrative review. *Nutrients* **13**, 1–40.
2. Thomas DT, Erdman KA & Burke LM (2016) Position of the academy of nutrition and dietetics, dietitians of Canada, and the American college of sports medicine: nutrition and athletic performance. *J Acad Nutr Diet* **116**, 501–528.
3. Galiuto L, Fedele E, Vitale E, et al. (2018) Healthy athlete's nutrition. *Med Sport: J Romanian Sport Med Soc* **14**, 2967–2985.
4. MacKenzie K, Slater G, King N, et al. (2015) The measurement and interpretation of dietary protein distribution during a Rugby Preseason. *Int J Sport Nutr Exerc Metab* **25**, 353–358.
5. Burke LM, Loucks AB & Broad N (2006) Energy and carbohydrate for training and recovery. *J Sport Sci* **24**, 675–685.
6. Venkatraman J & Pendergast T (2002) Effect of dietary intake on immune function in athletes. *Sport Med* **32**, 323–337.
7. Jenner SL, Buckley GL, Belski R, et al. (2019) Dietary intakes of professional and semi-professional team sport athletes do not meet sport nutrition recommendations – a systematic literature review. *Nutrients* **11**, 1–16.
8. Nepocatych S, Balilionis G, Hughes M, et al. (2014) Comparing dietary intake and body composition in female athletes during in- and off-season: 1469 Board #209 May 29, 08.00–09.30. *Med Sci Sport Exerc* **46**, 394.
9. Antonio J (2019) High-protein diets in trained individuals. *Res Sports Med* **27**, 195–203.
10. Heaney S, O'Connor H, Michael S, et al. (2011) Nutrition knowledge in athletes: a systematic review. *Int J Sport Nutr Exerc Metab* **21**, 248–261.
11. Trakman GL, Forsyth A, Middleton K, et al. (2018) Australian football athletes lack awareness of current sport nutrition guidelines. *Int J Sport Nutr Exerc Metab* **28**, 644–650.
12. Worsley A (2002) Nutrition knowledge and food consumption: can nutrition knowledge change food behaviour? *Asia Pac J Clin Nutr* **11**, S579–S585.
13. Birkenhead K & Slater L (2015) A review of factors influencing athletes' food choices. *Sports Med* **45**, 1511–1522.
14. Spronk I, Heaney S, Prvan T, et al. (2015) Relationship between general nutrition knowledge and dietary quality in elite athletes. *Int J Sport Nutr Exerc Metab* **25**, 243–251.
15. Trakman GL, Forsyth A, Hoye R, et al. (2017) The nutrition for sport knowledge questionnaire (NSKQ): development and validation using classical test theory and rasch analysis. *J Int Soc Sports Nutr* **14**, 1–11.

British Journal of Nutrition

16. Parmenter K & Wardle J (1999) Development of a general nutrition knowledge questionnaire for adults. *Eur J Clin Nutr* **53**, 298.

17. Zinn C, Schofield G & Wall C (2005) Development of a psychometrically valid and reliable sports nutrition knowledge questionnaire. *J Sci Med Sport* **8**, 346–351.

18. Trakman GL, Forsyth A, Hoye R, *et al.* (2018) Development and validation of a brief general and sports nutrition knowledge questionnaire and assessment of athletes' nutrition knowledge. *J Int Soc Sport Nutr* **15**, 1–8.

19. Heikkilä M, Valve R, Lehtovirta M, *et al.* (2018) Development of a nutrition knowledge questionnaire for young endurance athletes and their coaches. *Scand J Med Sci Sport* **28**, 873–880.

20. Tam RA, Gifford JM, Flood VT, *et al.* (2020) Development of an electronic questionnaire to assess sports nutrition knowledge in athletes. *J Am Coll Nutr* **39**, 1–9.

21. Trakman GL, Forsyth A, Devlin BL, *et al.* (2016) A systematic review of athletes' and coaches' nutrition knowledge and reflections on the quality of current nutrition knowledge measures. *Nutrients* **8**, 1–23.

22. Torres-McGehee TM, Pritchett KL, Zippel D, *et al.* (2012) Sports nutrition knowledge among collegiate athletes, coaches, athletic trainers, and strength and conditioning specialist (original research) (Report). *J Athletic Training* **47**, 205–211.

23. Spronk I, Kullen C, Burdon C, *et al.* (2014) Relationship between nutrition knowledge and dietary intake. *Br J Nutr* **111**, 1713–1726.

24. Riviere AJ, Leach R, Mann H, *et al.* (2021) Nutrition knowledge of collegiate athletes in the US and the impact of sports dietitians on related outcomes: a narrative review. *Nutrients* **13**, 1–11.

25. Moher D, Liberati A, Tetzlaff J, *et al.* (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. *PLoS Med* **6**, e1000097.

26. Moola S, Munn Z, Tufanaru C, *et al.* (2017) *Systematic Reviews of Etiology and Risk. Joanna Briggs Institute Reviewer's Manual.* Adelaide: The Joanna Briggs Institute.

27. Elias SSM, Saad HA, Taib MNM, *et al.* (2018) Effects of sports nutrition education intervention on sports nutrition knowledge, attitude and practice, and dietary intake of Malaysian team sports athletes. *Malaysian J Nutr* **24**, 103–116.

28. Allman K (2020) Nutritional intake in elite cross-country skiers. *Scan's Pulse* **40**, 17–18.

29. Dagcilar K & Ozturk M (2020) An evaluation of nutritional knowledge levels, nutritional intake, and anthropometric features of Northern Cyprus professional football players. *Med Dello Sport* **73**, 81–89.

30. Nascimento M, Silva D, Ribeiro S, *et al.* (2016) Effect of a nutritional intervention in athlete's body composition, eating behaviour and nutritional knowledge: a comparison between adults and adolescents. *Nutrients* **8**, 535.

31. Magee PJ, Gallagher AM & McCormack JM (2017) High prevalence of dehydration and inadequate nutritional knowledge among university and club level athletes. *Int J Sport Nutr Exerc Metab* **27**, 158–168.

32. Devlin BL, Leveritt MD, Kingsley M, *et al.* (2017) Dietary intake, body composition, and nutrition knowledge of Australian football and soccer players: implications for sports nutrition professionals in practice. *Int J Sport Nutr Exerc Metab* **27**, 130–138.

33. Jenner SL, Devlin BL, Forsyth AK, *et al.* (2020) Assessing the nutrition knowledge of professional female Australian football (AFLW) athletes. *Sci Medicind Football* **4**, 1–7.

34. Jenner SL, Trakman GL, Coutts A, *et al.* (2018) Dietary intake of professional Australian football athletes surrounding body composition assessment. *J Int Soc Sport Nutr* **15**, 1–8.

35. Lohman R, Carr A & Condo D (2019) Nutritional intake in Australian football players: sports nutrition knowledge and macronutrient and micronutrient intake. *Int J Sport Nutr Exerc Metab* **29**, 289–296.

36. Condo D, Lohman R, Kelly M, *et al.* (2019) Nutritional intake, sports nutrition knowledge and energy availability in female Australian rules football players. *Nutrients* **11**, 971–971.

37. Andrews MC & Itsiopoulos C (2016) Room for improvement in nutrition knowledge and dietary intake of male football (soccer) players in Australia. *Int J Sport Nutr Exerc Metab* **26**, 55–64.

38. Devlin B & Belski R (2015) Exploring general and sports nutrition and food knowledge in elite male Australian athletes. *Int J Sport Nutr Exerc Metab* **25**, 225–232.

39. Leite M, Machado AC, Silva DGD, *et al.* (2016) Nutritional knowledge after conducting nutritional education activities between children and adolescents sportspeople. *Pensar Prát* **19**, 56–67.

40. Balaravi B, Chin MQ, Karppaya H, *et al.* (2017) Knowledge and attitude related to nutritional supplements and risk of doping among national elite athletes in Malaysia. *Malaysian J Nutr* **23**, 409–423.

41. Burkhart SJ (2010) Assessment of Nutritional Knowledge and Food Skills in Talented Adolescent Athletes. Master's Thesis, Massey University. https://mro.massey.ac.nz/handle/10179/2356 (accessed May 2020).

42. Gonçalves CB (2009) Food consumption and understanding of the adapted food pyramid in physically active adolescents from the Federal District. Master's Thesis, Universidade de Brasília. https://repositorio.unb.br/handle/10482/3879 (accessed May 2020).

43. Nichols PE, Jonnalagadda SS, Rosenbloom CA, *et al.* (2005) Knowledge, attitudes, and behaviors regarding hydration and fluid replacement of collegiate athletes. *Int J Sport Nutr Exerc Metab* **15**, 515–527.

44. Öz F, Aydin R, Onsuz MF, *et al.* (2016) Development of a reliable and valid adolescence nutritional knowledge questionnaire. *Progression Nutr* **18**, 125–134.

45. Reilly C & Maughan R (2007) *The Development of a Reliable and Validated Questionnaire to Assess Sports Nutrition Knowledge.* Loughborough: Loughborough University.

46. Shifflett B, Timm C & Kahanov L (2002) Understanding of athletes' nutritional needs among athletes, coaches, and athletic trainers. *Res Q Exerc Sport* **73**, 357–362.

47. Zawila LG, Steib CSM & Hoogenhoom B (2003) The female collegiate cross-country runner: nutritional knowledge and attitudes. *J Athletic Training* **38**, 67–74.

48. Calella P, Iacullo VM & Valerio G (2017) Validation of a General and Sport Nutrition Knowledge questionnaire in adolescents and young adults: GESNK. *Nutrients* **9**, 439.

49. Coccia C, Fernandes SM & Altiti J (2020) Tweeting for nutrition: feasibility and efficacy outcomes of a 6-week social media-based nutrition education intervention for student-athletes. *J Strength Condit Res* **34**, 2084–2092.

50. Abbey EL, Wright CJ & Kirkpatrick CM (2017) Nutrition practices and knowledge among NCAA Division III football players. *J Int Soc Sports Nutr* **14**, 1–9.

51. Madrigal L, Wilson PB & Burnfield JM (2016) Nutritional regrets and knowledge in national collegiate athletic association division i athletes: establishing a foundation for educational interventions. *J Issues Intercollegiate Athlet* **9**, 1–16.

52. Saribay AK & Kirbaş Ş (2019) Determination of nutrition knowledge of adolescents engaged in sports. *Univ J Educ Res* **7**, 40–47.

53. Simpson A, Gemming L, Baker D, *et al.* (2017) Do image-assisted mobile applications improve dietary habits,

knowledge, and behaviours in elite athletes? A pilot study. *Sports* **5**, 60.

54. Andrews A, Wojcik JR, Boyd JM, *et al.* (2016) Sports nutrition knowledge among mid-major division I University Student-Athletes. *J Nutr Metab* **2016**, 5.

55. Werner EN, Guadagni AJ & Pivarnik JM (2020) Assessment of nutrition knowledge in division I college athletes. *J Am Coll Health* (Epublication ahead of print version 2 April 2020).

56. Judge LW, Kumley RF, Bellar DM, *et al.* (2016) Hydration and fluid replacement knowledge, attitudes, barriers, and behaviors of NCAA division 1 American football players. *J Strength Condit Res* **30**, 2972–2978.

57. Mitchell BA, Holden SL, Forester BE, *et al.* (2016) Nutritional education intervention and the effects on nutritional knowledge of male college athletes. *Appl Res Coaching Athletics Ann* **31**, 207–223.

58. Rossi FE, Landreth A, Beam S, *et al.* (2017) The effects of a sports nutrition education intervention on nutritional status, sport nutrition knowledge, body composition, and performance during off season training in NCAA Division I Baseball Players. *J Sports Sci Med* **16**, 60–68.

59. Holden SL, Forester BE, Smith AL, *et al.* (2018) Nutritional knowledge of collegiate athletes. *Appl Res Coaching Athletics Ann* **33**, 65–77.

60. McCrink CM, McSorley EM, Grant K, *et al.* (2020) An investigation of dietary intake, nutrition knowledge and hydration status of Gaelic Football players. *Eur J Nutr* **30**, 30.

61. Murphy J & O'Reilly J (2020) Nutrition knowledge and dietary intake of hurlers. *Int J Sport Sci Coaching* **3**, 690–700.

62. Renard M, Kelly DT, Cheilleachair NN, *et al.* (2020) Evaluation of nutrition knowledge in female gaelic games players. *Sports* **8**, 29.

63. Argôlo D, Borges J, Cavalcante A, *et al.* (2018) Poor dietary intake and low nutritional knowledge in adolescent and adult competitive athletes: a warning to table tennis players. *Nutr Hosp* **35**, 1124–1130.

64. Blennerhassett C, McNaughton LR, Cronin L, *et al.* (2019) Development and implementation of a nutrition knowledge questionnaire for ultraendurance athletes. *Int J Sport Nutr Exerc Metab* **29**, 39–45.

65. Hardy R, Kliemann N, Evansen T, *et al.* (2017) Relationship between energy drink consumption and nutrition knowledge in student-athletes. *J Nutr Educ Behav* **49**, 19–26.e11.

66. Trakman G, Brown F, Forsyth A, *et al.* (2019) Modifications to the nutrition for sport knowledge questionnaire (NSQK) and abridged nutrition for sport knowledge questionnaire (ANSKQ). *J Int Soc Sports Nutr* **16**, 1–3.

67. Burke LM, Loucks AB & Broad N (2006) Energy and carbohydrate for training and recovery. *J Sports Sci* **24**, 675–685.

68. Steffl M, Kinkorova I, Kokstejn J, *et al.* (2019) Macronutrient Intake in Soccer Players – a meta-analysis. *Nutrients* **11**, 09.

69. Devlin BL (2016) Modifiable Factors that a Sports Nutrition Professional can Influence in a Team-Based Sport Setting: Recognising Individual Differences and Highlighting the Importance of Personalised Nutrition. PhD, La Trobe University. http://hdl.handle.net/1959.9/559205 (accessed April 2020).

70. Jenner S, Belski R, Devlin B, *et al.* (2021) A qualitative investigation of factors influencing the dietary intakes of professional Australian football players. *Int J Environ Res Public Health* **18**, 1–15.

71. Trakman GL (2018) The Development and Validation of the Nutrition for Sport Knowledge Questionnaire (NSKQ) and Abridged Nutrition for Sport Knowledge Questionnaire (A-NSKQ) to Investigate the Sports Nutrition Knowledge of Australian Athletes. PhD, La Trobe University. http://hdl.handle.net/1959.9/564473 (accessed April 2020).

72. Capling L, Beck KL, Gifford JA, *et al.* (2017) Validity of dietary assessment in athletes: a systematic review. *Nutrients* **9**, 1–26.