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# NUTRITION KNOWLEDGE AND SKILLS AMONG YOUNG ENDURANCE ATHLETES

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Department of Food and Nutrition
University of Helsinki
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# NUTRITION KNOWLEDGE AND SKILLS AMONG YOUNG ENDURANCE ATHLETES

**Maria Heikkilä**

ACADEMIC DISSERTATION

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*Knowing is not enough; we must apply*
*Willing is not enough; we must do*

Johann Wolfgang von Goethe

## Abstract

Nutrition plays an important role in athletic performance. Its full potential is rarely realized due to limited nutrition knowledge among athletes and their coaches. Misunderstandings and gaps in knowledge can lead to food choices that do not support athletic development. This thesis study was undertaken to gain further insight into the nutrition knowledge of young Finnish endurance athletes. Another aim was to evaluate how athletes' knowledge and nutritional skills can be improved.

Study I created and validated a questionnaire measuring knowledge in different areas of sports nutrition. This questionnaire was then used in Study II, which aimed to measure the nutrition knowledge of young Finnish endurance athletes and their coaches. The results of Study II were used to develop an education intervention, aiming to improve athletes' nutrition knowledge and dietary intake, in Study III. The intervention compared the effects of participatory nutrition sessions alone to those enhanced by a mobile app.

In Study II, a total of 312 athletes and 94 coaches completed the questionnaire. The athletes were 17.9±1.2 and the coaches 44.3±12.3 years old. Half of the athletes were women and half men; of the coaches 27% were women. Of the athletes 36% were cross country skiers, 35% orienteers and the rest other endurance athletes.

Seventy-nine athletes took part in the intervention in Study III. Their mean age was 18.0±1.4 years, 56% of them were men and 44% were women, and 42% were cross-country skiers. The education in the intervention was based on the Self-Determination Theory and the concept of meaningful learning processes. The education sessions included discussions, tasks and goal setting, which were all intended to increase the athletes' intrinsic motivation. This motivation in turn is a prerequisite for effective learning. The three sessions lasted 90 minutes each and were held fortnightly. The athletes filled in the questionnaire at baseline and a week and three months after the last session. The athletes in the mobile app group used the app for four days after each session and took photos of everything they ate or drank. Both groups completed a three-day food diary at baseline and three months after the last session and received personal feedback on it.

On average, the athletes in Study II answered 73% and the coaches 81% of the items correctly. However, over a half of the athletes and 44% of the coaches scored below the mean knowledge score, at worst answering only 47% of the items correctly. The coaches scored better in all sections of the questionnaire. The questions in the 'Dietary supplements' section proved to be the most difficult for the athletes, and those in the ‘Nutrition recommendations for endurance athletes’ section for the coaches. The older the athletes were, the higher was their mean nutrition knowledge score. Among the coaches, the situation was the opposite. On average, the female athletes and coaches scored better than the men. The athletes who were part of a national team had higher knowledge scores than those who were not.

The athletes’ nutrition knowledge improved significantly during the intervention. At baseline, their knowledge score was 78%. A week after the education sessions, the athletes in the mobile app group answered on average 87% of the questions correctly and three months later, 86%. In the group without the mobile app, the scores were 85% and 84%, respectively. There was no significant difference between the groups in any sections of the questionnaire. The mean energy intake of the athletes was below the estimated energy expenditure during Study III. The intake of protein and fat met the recommendations for endurance athletes, but the intake of carbohydrates was below them (6–10 $g \cdot kg^{-1} \cdot day^{-1}$) throughout the study, even though it slightly improved. At the end of the intervention, the athletes in the mobile app group consumed 5.4 $g \cdot kg^{-1} \cdot day^{-1}$ of carbohydrates and the athletes in the other group 5.0 $g \cdot kg^{-1} \cdot day^{-1}$. Many psychological, social and economic factors affect what we eat. Improved knowledge does not automatically lead to better food choices if the intention to perform the behavioural change is lacking. The duration of the intervention may also have been too short for notable behavioural changes. In addition, already at the beginning of the study the diet of the athletes was better than that of the general Finnish population, thus leaving less room for dietary improvements.

Nutrition knowledge improved after only three education sessions and food diary feedback, but the mobile app did not further improve this learning. Thus, if sport clubs and other sport organizations dedicated even a relatively small amount of time and other resources to structured, targeted, motivational and science-based nutrition education, it may promote positive changes in nutrition knowledge. As athletes make use of the skills they learn during their sports careers in their everyday lives as well as when training other athletes, receiving influential nutrition education could also benefit their performance and health in the future.

Key words: nutrition knowledge, sport nutrition, education intervention, endurance athletes, adolescents

## Tiivistelmä (Finnish abstract)


Hyvä ravitsemustila vaikuttaa merkittävästi urheilijan terveyteen, kehittymiseen, suorituskykyyn ja palautumiseen. Merkitys voi kuitenkin jäädä epäselväksi urheilijoille ja valmentajille, sillä heidän ravitsemustiedoissaan on usein puutteita. Harhaluulot ja väärinymmärrykset voivat johtaa ruokavalintoihin, jotka eivät tue urheilemista parhaalla mahdollisella tavalla. Tässä tutkimuksessa selvitettiin, millaista nuorten suomalaisten kestävyysurheilijoiden ravitsemusosaaminen on ja miten ravitsemukseen liittyviä tietoja ja taitoja voidaan parantaa.

Tutkimuksen alussa luotiin ja validoitiin kyselylomake mittaamaan osaamista urheiluravitsemuksen eri osa-alueilla (julkaisu I). Kyselytutkimukseen osallistui 312 urheilijaa ja 94 valmentajaa (julkaisu II). Sen tuloksiin pohjautuen suunniteltiin luentomallista ravitsemusohjausta sekä mobiilisovellusta hyödyntävä ravitsemusinterventio, jolla urheilijoiden ravitsemustietoihin ja ruokavalintoihin pyrittiin vaikuttamaan (julkaisu III).

Kyselytutkimukseen osallistuneet urheilijat olivat iältään 17.9±1.2-vuotiaita, ja heistä 36 % oli maastohiihtäjiä, 35 % suunnistajia ja loput muita kestävyysurheilijoita. Puolet urheilijoista oli naisia ja puolet miehiä. Valmentajat olivat 44.3±12.3-vuotiaita ja heistä 27 % oli naisia. Ravitsemusinterventioon osallistui 79 urheilijaa. Urheilijat olivat keskimäärin 18±1.4-vuotiaita ja heistä 42 % oli maastohiihtäjiä. Urheilijoista 56 % oli miehiä ja 44 % naisia. Ravitsemusohjauksen pohjana oli mielekkään oppimisen teoria ja itseohjautuvuusteoria. Tehtävillä ja keskusteluilla pyrittiin vahvistamaan osallistujien autonomian tunnetta ja motivaatiota. Ohjaus koostui kolmesta 90-minuuttisesta vuorovaikutteisesta luennosta, jotka pidettiin kahden viikon välein. Urheilijat täyttivät ravitsemusosaamiskyselyn intervention alussa, viikon sekä kolmen kuukauden kuluttua viimeisestä luennosta. Toinen ryhmä käytti jokaisen luennon jälkeen mobiilisovellusta, jolla kuvattiin kaikki syömiset ja juomiset neljän päivän ajan sekä tehtiin näihin liittyviä tehtäviä. He saivat sovelluksen kautta henkilökohtaista palautetta ruokavaliostaan. Molemmat ryhmät täyttivät lisäksi kolme vuorokautta ruokapäiväkirjaa tutkimuksen alussa ja lopussa ja saivat tästä henkilökohtaista palautetta.

Kyselytutkimuksessa urheilijat vastasivat keskimäärin 73 % ja valmentajat 81 % kysymyksistä oikein, mutta vaihtelu oli suurta. Heikoimmillaan urheilijat vastasivat alle puoliin kysymyksistä oikein. Valmentajien ravitsemusosaaminen oli parempaa kaikilla kyselyn osa-alueilla. Haasteellisimmiksi osoittautuivat ravintolisiin ja urheilijoiden ravitsemussuosituksiin liittyvät väittämät. Nuoremmilla urheilijoilla oli ravitsemustiedoissaan enemmän puutteita kuin vanhemmilla; valmentajilla

tilanne oli päinvastainen. Naisurheilijat ja -valmentajat saivat keskimäärin miehiä parempia tuloksia. Maajoukkueisiin kuuluvat urheilijat saivat enemmän oikeita vastauksia kuin urheilijat, jotka eivät kuuluneet vastaaviin valmennusryhmiin.

Urheilijoiden ravitsemustiedot paranivat merkittävästi intervention aikana. Tutkimuksen alussa urheilijat vastasivat 78 % kysymyksistä oikein. Viikko luentojen jälkeen oikeita vastauksia oli mobiilisovellusryhmässä keskimäärin 87 % ja kolmen kuukauden päästä 86 %. Ryhmässä, jossa mobiilisovellus ei ollut käytössä, vastaavat osaamisprosentit olivat 85 ja 84 %. Ryhmien välillä ei ollut tilastollisesti merkitsevää eroa missään kyselyn osa-alueessa. Urheilijoiden keskimääräinen energiansaanti jäi alle arvioidun kokonaisenergiankulutuksen, vaikka se tutkimuksen aikana hieman paranikin. Proteiineja ja rasvoja saatiin kestävyys-urheilijoiden ravitsemussuositusten mukaisesti, mutta hiilihydraatinsaanti jäi suosituksesta (6–10 $g \cdot kg^{-1} \cdot vrk^{-1}$), vaikka se intervention aikana hieman nousikin. Mobiilisovellusryhmässä urheilijat saivat hiilihydraatteja 5,4 $g \cdot kg^{-1} \cdot vrk^{-1}$ intervention lopussa ja toisessa ryhmässä 5,0 $g \cdot kg^{-1} \cdot vrk^{-1}$. Ruokavalintoihin vaikuttavat monet psykologiset, sosiaaliset ja taloudelliset tekijät. Parantuneet tiedot eivät suoraan johda parempiin ruokavalintoihin, jos riittävää motivaatiota käyttäytymisen muutokseen ei ole. Muutokset myös tapahtuvat usein pitkän ajan kuluessa, miksi intervention lyhyt kesto voi selittää sen, ettei ruokavalioissa tapahtunut tilastollisesti merkitseviä muutoksia. Lisäksi urheilijat söivät jo lähtötilanteessa paremmin kuin suomalaiset keskimäärin.

Tämän tutkimuksen perusteella nuorten urheilijoiden ravitsemustietoja on mahdollista parantaa huolellisesti suunnitellulla, vuorovaikutteisella, ryhmässä tapahtuvalla ravitsemusohjauksella. Jo kolme ravitsemusohjaustapaamista sekä henkilökohtainen palaute ruokapäiväkirjoista paransivat urheilijoiden ravitsemustietoja merkittävästi. Mobiilisovelluksen käyttäminen ei parantanut osaamista verrattuna toiseen ryhmään. Suhteellisen pienellä ajan- ja muiden resurssien käytöllä voidaankin saada aikaan merkittäviä muutoksia ravitsemusosaamisessa, mikä toivottavasti kannustaa lisäämään ravitsemusohjausta urheilujärjestöissä. Urheilijat voivat myös hyödyntää oppimiaan taitoja myöhemmin uransa aikana sekä sen jälkeen, mikä voi näkyä heidän suorituskyvyssään ja terveydessään. Heidän on lisäksi mahdollista toimia esimerkkeinä kanssaurheilijoilleen sekä auttaa ravitsemukseen liittyvien harhaluulojen torjumisessa.

Avainsanat: ravitsemusosaaminen, urheiluravitsemus, ravitsemusinterventio, kestävyysurheilu, nuoret

## Contents

## List of original publications

This thesis is based on the following publications:

| | |
|---|---|
| I | Heikkilä M, Valve R, Lehtovirta M, Fogelholm M. Development of a nutrition knowledge questionnaire for young endurance athletes and their coaches. Scandinavian Journal of Medicine and Science in Sports. 2018;28:873-880. |
| II | Heikkilä M, Valve R, Lehtovirta M, Fogelholm M. Nutrition Knowledge Among Young Finnish Endurance Athletes and Their Coaches. International Journal of Sport Nutrition and Exercise Metabolism. 2018;12:1-6 |
| III | Heikkilä M, Lehtovirta M, Autio O, Fogelholm M, Valve R. The Impact of Nutrition Education Intervention with and Without a Mobile Phone Application on Nutrition Knowledge Among Young Endurance Athletes. Nutrients. 2019;11:2249. |

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## Abbreviations

| | |
|---|---|
| ACSM | American College of Sports Medicine |
| APP | Application (for mobile devices) |
| ATP | Adenosine triphosphate |
| BMI | Body mass index |
| CBT | Cognitive Behavioural Therapy |
| CI | Confidence interval |
| COPE | Creation Opportunities to Personal Empowerment |
| DE | Disordered eating |
| EA | Energy availability |
| EB | Energy balance |
| ED | Eating disorder |
| EDNOS | Eating disorders not otherwise specified |
| EDU | Group with participatory nutrition education sessions |
| EDU+APP | Group with participatory nutrition education sessions and the use of the mobile app |
| EEE | Exercise energy expenditure |
| EI | Energy intake |
| FFM | Fat-free mass |
| FFQ | Food frequency questionnaire |
| FSH | Follicle-stimulating hormone |
| LEA | Low energy availability |
| LH | Luteinizing hormone |
| RED-S | Relative Energy Deficiency in Sports |
| REE | Resting energy expenditure |
| SCT | Social Cognitive Theory |
| SD | Standard deviation |
| SDT | Self-Determination Theory |
| TEE | Total energy expenditure |

# 1 Introduction

*'The winners will, without doubt, be highly talented, highly trained and highly motivated. At one time that would have been enough. But these days it is highly likely that everyone in the race will have these qualities.......where everyone else is equal, it is diet that will make the vital difference.'* Prof. Ron Maughan 1995[1]

Regardless of an athlete's age, optimal athletic development, performance, recovery and overall health are made up of three equally important factors: training, rest and nutrition (Figure 1). Elite athletes are not made with a poor diet. Attention should especially be paid to adequate energy and nutrient intake, hydration and the timing of meals.[2] Unsuitable nutrition before, after and during training or a competition may impair performance and recovery.


**Figure 1.** Training, rest and proper nutrition – the keys to athletic development. Figure inspired by the Finnish 'Healthy Athlete Program' of the UKK Institute – Centre for Health Promotion Research.[3]

Proper nutrition and adequate knowledge of sports nutrition plays a crucial role among young athletes. First, due to the high energy and nutrient demands of activity, a sufficient amount of both is needed for normal physical growth and health, biological maturation and behavioural development.[4,5] Second, many elite athletes are willing to take risks to reach their maximal performance, for example, to control their body weight or shape with extreme dietary or training methods or to excessively use dietary supplements.[2,6] Athletes grow into the culture of risk, as high-performance careers are often chosen already at a young age.[6] In addition, it is common behaviour for adolescents to question rules and norms, which can also lead them to risky behaviour. Adolescents are especially prone to the negative consequences of risking their health during training and competitions, as they are not physically or psychologically mature.[6] Third, the amount of training in various sports, such as endurance sports can already be at a high level in junior series, leading to great energy demands already at a young age.

Endurance sports include many different sports, such as distance running, race-walking, cycling, triathlons, rowing, cross-country skiing, biathlons, and orienteering. According to a typical definition, endurance translates into resistance to fatigue, and endurance exercise is an exercise that lasts for 30 minutes or longer.[7] However, the resistance to fatigue is also important in shorter but intense exercises, such as in a 3000-metre run and therefore these are also regarded as endurance exercises. Exercise lasting longer than 4–5 hours is referred to as ultra-endurance exercise. In Finland in 2019, athletics, cross-country skiing and biathlon were among the most popular endurance sports among the adult population.[8]

The coaching of Finnish, young elite endurance athletes is typically organized by the elite training groups of different sport associations or federations; by sports academies, including sports high schools; and in the Finnish Military Sport Federation. In addition, athletes must be part of a sports club in order to be able to compete. Over 6000 high-school aged athletes belong to Finnish sports academies.[9] The aim of the sports academy network is to ensure that the coaching of athletes is on a solid basis and that athletes are offered an operational environment in which they can fulfill their potential in sports and other walks of life. Coach education in Finland is organized by, for example, different sports associations or federations, sports institutes, universities of applied sciences, and the University of Jyväskylä.

In exercise, resistance to fatigue is an important factor. Fatigue is typically caused by substrate depletion, mostly muscle glycogen depletion, reduced blood glucose concentrations or dehydration.[10] Thus, among the main nutritional strategies for optimizing endurance performance are adequate intakes of carbohydrates and fluids. In addition to nutrient-dense carbohydrates and hydration, the importance of high-quality protein, vitamin D, calcium and iron for young athletes should be emphasized.[4] An endurance athlete must also concentrate on adequate energy intake. The energy requirements of endurance training can easily be double or even as high as quadruple that of sedentary individuals or athletes performing only low activity training.[11] These high energy demands are due to long, high-intensity endurance exercises. Even for young competitive endurance athletes, it is typical to train twice a day. Inadequate energy intake does not support the bodily functions needed for optimal health, growth and performance.[12]

It is important that athletes learn the importance of nutrition already at the beginning of their athletic career. This can help them avoid the risks caused by, for example, low energy availability, inadequate nutrient intakes, and overplaying dietary supplements and energy drinks.[4] It can also reduce their nutrition-related misunderstandings and gaps in their knowledge, which are typically in relation to energy, proteins and dietary supplements.[13] Unfortunately, both athletes' and coaches' nutrition knowledge is limited.[14] Nutrition knowledge is one of the factors behind our food choices[15] and can thus also have an indirect but significant effect on athletic performance.

This doctoral thesis aims to investigate nutrition knowledge and skills among young, approximately 16–20-year old Finnish endurance athletes. It also studies the nutrition knowledge of their coaches. The thesis consists of three papers, the first of which explains the creation and validation process of a sport nutrition knowledge questionnaire. The two latter papers investigate the level of nutrition knowledge and whether this, together with dietary intake, can be improved through an education intervention comparing the effect of participatory nutrition education sessions to sessions complemented with the use of a mobile food application. The literature review of this thesis presents in detail the nutritional aspects that were emphasized in the nutrition education and the nutrition knowledge questionnaires.

# 2 Review of the literature

## 2.1 Nutrition and athletic development of young endurance athletes

The benefits of training, rest and proper nutrition for health and athletic performance are evident. Incorrect nutrition may impair performance and recovery from training and competitions. For young athletes, nutrition also plays an important role in normal growth and development.[2] Thus, it is essential that athletes, their coaches and parents understand the important role of nutrition in athletic development already when athletes are young.

The foundations of the lifelong relationship with food are created in adolescence.[16] This has a significant effect on later food habits, attitudes and body image. It might also be beneficial in preventing or reducing the risk of different diseases later in life.[17] Adolescence can also be seen as a critical time of exposure to different good and bad beliefs and food practices due to increasing independency and peer pressure.[2,16] Therefore, already at the beginning of their careers, athletes should learn the importance of adequate energy and nutrient intake, hydration and the timing of meals.[2]

In addition to what an athlete eats and drinks, it is important that the timing of food consumption is sound. Pre-event meals, low in fat and fibre but high in carbohydrates and fluids and moderate in proteins, are recommended 3–4 hours before competitions and high-intensity training.[2,5] When the training lasts less than 3 hours, a smaller snack or liquid meal is a suitable choice.[5] Finding individual timings of pre-event meals is important to minimize gastric distress and nausea during training. For the same reason, excess fat and fibre should be avoided before training.[2,5] Within 30 minutes of training, a snack with carbohydrates and proteins is recommended to replenish glycogen stores and to ensure muscle repair. A post-event meal should be consumed again within 1–2 hours of activity to enhance recovery processes.[5] In long and high-intensity endurance training, the use of sport drinks or other carbohydrate sources is recommended to maintain an optimal blood glucose level and to prevent fatigue.[2,5]

According to the International Olympic Committee consensus statement of 2015[4] on youth athletic development, the following nutritional factors should be taken into account when developing healthy, resilient, capable and successful athletes:

1) Young athletes' dietary education should emphasize the optimal eating patterns that support health, normal growth and development, and sport participation

demands. Special attention should be paid to a balanced intake of nutrient-dense **carbohydrates**, high-quality **protein** and adequate dietary **calcium**, **vitamin D** and **iron** intakes.
2) The potential risks of **dietary supplements** and **energy drinks** should be taught to young athletes and their support personnel.
3) The risks of **relative energy deficiency in sports** (RED-S) and sport-related **eating disorders** (EDs) and **disordered eating** (DE) should be emphasized and mitigated. That can be done by improving education and thus raising awareness of the problem, by improving screening and treatment, and by modifying some sports rules.[4]

The above-mentioned nutritional aspects, complemented with water and hydration, have also been highlighted in other studies explaining the main nutritional considerations of young athletes.[5,16–18] Thus, the following chapters will concentrate on the above-mentioned nutritional aspects.

It should be noted that most of the knowledge regarding sports nutrition, training and performance is obtained from studies of adults.[17] Research on young athletes has been much more limited, partly due to research ethics, as it is recommended that only non-invasive techniques are used in studies of youths. As a consequence, nutrition recommendations for adolescent athletes are mainly based on findings among adult athletes. Attention should also be paid to the fact that considerably less research has been conducted among women than men.[19] Therefore, the fact should not be overlooked that women may have unique nutritional issues due to reproductive hormones, which may lead to differences in fuel metabolism between the two sexes. Eumenorrhoeic, amenorrhoeic, oligomenorrhoeic, hormonal contraceptive users and postmenopausal athletes may all have slightly different nutritional needs. However, more high-quality research is needed to confirm the possible differences in nutritional needs and thus this literature review discusses no sex-specific recommendations for macronutrients. However, in micronutrient, such as iron and calcium, and energy requirements, the differences between the two sexes are generally accepted and are thus discussed in this literature review.

## 2.2 Energy metabolism during endurance exercise

Physical training refers to the capacity of the skeletal muscles to adapt to repeated physical activities over a longer time period so that exercise capacity improves as a result.[20] This kind of training initiates multiple physiological and metabolic adaptations in the working muscles that subsequently increase the adenosine triphosphate (ATP) production rates from both anaerobic and aerobic pathways, match the production and hydrolysis of ATP, improve resistance to fatigue, and minimize cellular disturbances.[21] Most of the effects of training on cellular homeostasis and muscle substrate stores occur during activity, but some of the important signalling pathways for training adaptations occur during the first 24 h of recovery. Optimal adaptation to training requires sensible training and nutrition strategies. It is important that the diet can sustain muscle energy stores, replenish energy reserves after training, and maintain performance during prolonged exercise.

Athletes obtain energy from macronutrients, i.e. carbohydrates, protein and fat, which all have specific metabolic or structural functions in the body. Carbohydrates are the main energy sources for athletes.[5] The performance of prolonged sub-maximal or intermittent high-intensity training and recovery from training is reduced if carbohydrate availability is insufficient.[22] Proteins are needed for growth, building and repairing tissues, and producing hormones and enzymes, for example, but less seldom for providing energy during training.[2,23] Fat is needed for energy production, for providing essential fatty acids and ensuring fat-soluble vitamin absorption, and for protecting organs and providing insulation.[2]

The energy systems for fuelling the working muscles are the phosphagen, glycolytic and oxidative pathways, which operate in parallel in the body.[24] The phosphagen system is the main source of energy production in very short (lasting only a few seconds) but high-intensity activities, such as weight lifting. The anaerobic glycolytic pathway is the main source of energy production in events that last 60–180 seconds, such as short sprints. The oxidative pathway is used as the main source of energy production in events lasting more than 2–3 minutes. Nevertheless, such activities do not solely rely on either the aerobic or anaerobic pathway for ATP production. Depending on, for example, the intensity, duration and frequency of training and prior nutrient intake, either the aerobic or anaerobic pathway dominates.

In endurance sports, the oxidative pathway is the main metabolic pathway that supports the fuelling of muscles.[24] Endurance training consists of exercises lasting 30 minutes or longer.[7] Typical endurance sports are, for example, distance running, race-walking, orienteering, cycling, triathlon, rowing, cross-country skiing, and biathlon. The substrates included in the oxidative pathway are derived from macronutrients and are mainly glycogen from the muscles and liver; triglycerides from the muscles, blood and adipose tissue; and, in smaller amounts, amino acids from the muscles, blood, liver and gut.[24] Depending on oxygen availability to the working muscles, either the aerobic or anaerobic pathway for ATP production dominates. The higher the intensity of training, the greater the proportion of energy that comes from carbohydrates and the less free fatty acids or intramuscular triglycerides are oxidized. Carbohydrates provide approximately 50–60% of energy during a 1–4-hour training session at 70% of maximal oxygen capacity; the rest of the energy is provided from free fatty acid oxidation. When the intensity of training decreases, more free fatty acids are used for energy production. Aerobic endurance training may lead to better utilization capacity of fat, which helps maintain glycogen stores for longer during prolonged exercise.

## 2.3 Energy intake and expenditure

The key factor in athletes' nutrition is adequate energy intake[24] as this promotes optimum athletic performance. Athletes need enough energy to be able to train, to maintain suitable weight and body composition and for normal bodily functions such as maintaining health, growth and immunity.[11,24] For young athletes, adequate energy intake is particularly important to sustain optimal physical growth and health, biological maturation and behavioural development.[4,5] The energy requirements of adolescent athletes are hard to define precisely[4,16] because metabolic variability is great within and between adolescent individuals, mainly due to the different stages of growth spurts[18] and because of the methodological challenges in estimating energy intakes and expenditures.[25]

The type of exercise, sex, heredity, age, body size and fat-free mass (FFM) have an effect on energy expenditure.[24] Growth spurts increase the energy needs of young athletes.[5] The energy requirements of different sports vary considerably. Endurance athletes train a great deal, frequently and at quite high intensities, already at a young age. Their energy requirement may be even four-fold compared to sedentary individuals or athletes performing only low activity training.[11] This must be taken into account in their nutritional counselling. For some athletes engaged in high volume or intense training, adequate energy intake may be hard to meet with a well-balanced diet alone, because of high energy consumption, suppressed appetite due to intense training, tight training schedules and the fear of gastrointestinal distress during training after a meal.[26] Thus, meal times should be planned carefully and nutrient-dense snacks should always be available.

Energy expenditure consists of four major factors: resting energy expenditure (REE)/basal metabolic rate, the thermic effect of food, the energy requirement of growth and maturation, and the thermic effect of activity.[17] Accurate energy expenditure can only be measured in fully-equipped laboratories and thus energy expenditure is typically only estimated by an equation.[24] For example, the Harris-

Benedict equation may be used for estimating REE. REE is then multiplied by an appropriate activity factor to estimate the total energy expenditure (TEE) of an athlete. For young endurance athletes, activity factors of 1.8 to 2.3, for example, may be used depending on their training amounts.

*Females: REE* ($kcal \cdot day^{-1}$) $= 9.56 \cdot kg + 1.85 \cdot cm - 4.68 \cdot age + 655.1$
*Males: REE* ($kcal \cdot day^{-1}$) $= 13.75 \cdot kg + 5.0 \cdot cm - 6.76 \cdot age + 66.47$

Adequate energy consumption is usually presented as either energy balance (older concept) or energy availability (newer concept).[11] Energy availability (EA) refers to the amount of dietary energy that is left after exercise training for other metabolic processes in the body and is normalized to fat-free mass. Energy balance refers to the amount of dietary energy added or lost from the energy stores of the body. Energy intake is typically derived from weighed or measured food records or a 24-hour recall.[27] In an energy balanced state (EB = 0 $kcal \cdot day^{-1}$) EA is around 45 $kcal \cdot kg\ FFM^{-1} \cdot day^{-1}$ in healthy young adults. A lower threshold for energy availability in females has been set to 30 $kcal \cdot kg\ FFM^{-1} \cdot day^{-1}$. Below this, impairments may occur in various bodily functions. Moderate EA is 30–45 $kcal \cdot kg\ FFM^{-1} \cdot day^{-1}$ and optimal >45 $kcal \cdot kg\ FFM^{-1} \cdot day^{-1}$.[28] Although a threshold value of 30 $kcal \cdot kg\ FFM^{-1} \cdot day^{-1}$ has been used to characterize women at risk of problems related to LEA, especially in larger studies, it has not gained uniform support.[29] First, the individual variability of LEA is high. Second, men are more resistant to its harmful effects. In fact, no threshold value has been suggested for men.

*Energy availability (EA) = (energy intake (EI) (kcal) – exercise energy expenditure (EEE) (kcal)) / Fat free mass (FFM) (kg)*

*Energy balance (EB) = energy intake (EI) (kcal) – total energy expenditure (TEE) (kcal)*

However, it should be noticed that for two reasons, it is not easy to determine whether the energy availability of an athlete is adequate.[30] Firstly, the standardized or reference protocols for energy availability assessments are lacking. Secondly, the reliability and validity of the metrics needed for assessing, for example, energy intake, energy expenditure and fat free mass, are questionable. It is not, after all, clear how much the newer concept of energy availability actually adds to the older concept of energy balance.

It is important to find a balance in optimal energy intake and expenditure. Long-term excess energy intake may result in overweight and obesity, metabolic disorders and increased risk of injury.[5,16] However, for many athletes, the opposite situation applies. It has been shown that many athletes are deficient in energy, especially in the form of carbohydrates.[11] This may promote impairments in performance and health and losses in lean tissue mass because even lean tissue is then used as fuel during exercise.[11,24] This may cause loss of strength and endurance and impairments in immune, endocrine and musculoskeletal functions, both through poor nutrient intake.[24] In addition, LEA in young athletes may delay puberty, as both increase the risk of menstrual irregularities, injuries, short stature, impaired bone health, and the development of DE.[16,19] Many female athletes in particular have deficient energy intakes.[11] Indeed, LEA has been defined as the main nutritional concern of female athletes.[24] However, in both sexes, LEA, relative energy deficiency in sports (RED-S) and DE are closely interwoven.

### 2.3.1 Relative Energy Deficiency in Sports (RED-S)

Low energy availability is considered an aetiological factor of a syndrome called RED-S.[12] According to the International Olympic Committee Consensus Statement[12] the RED-S syndrome refers to 'impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis and cardiovascular health caused by relative energy deficiency'. Earlier, the interrelationship of the three components – low energy availability (with or without DE), menstrual function and bone mineral density – was referred to as the Female Athlete Triad.[12,31,32] The concept of RED-S was introduced in 2014 as it was recognized that relative energy deficiency also affects men and is connected to much wider health concerns than only the components of the Female Athlete Triad.

In both sexes, the cause of RED-S is an imbalance between the athlete's energy intake and energy expenditure through sports.[30] This leads to inadequate energy to support the bodily functions needed for optimal health and performance.[12] Most of the literature on LEA has focused on female athletes even though health risks occur and the risk sports are the same among male athletes. However, the biological responses to energy deficiency among men and women are likely to be different. The main health concerns among men are considered to be LEA, reduced sex hormones (testosterone) and impaired bone health.[32]

Among the risk sports for RED-S are weight-sensitive sports, in which weight is seen as an important factor in performance, appearance or requirement for a target weight category in a competition.[33] Weight-sensitive sports are further classified into three categories: 1) gravitational sports (e.g. running, cross-country skiing, ski jumping, cycling and other sports in which the body must be moved against gravity), 2) weight-class sports (e.g. wrestling and judo) and 3) aesthetically judged sports (e.g. figure skating and gymnastics).

RED-S has a wide range of health concerns and potential indirect performance-impairing consequences.[30] *Health concerns* are summarized in Figure 2 and described briefly below. The RED-S factors negatively affecting performance are increased injury risk, decreased training response, coordination and concentration, impaired judgement, irritability, depression, and decreases in glycogen stores, muscle strength and endurance performance.

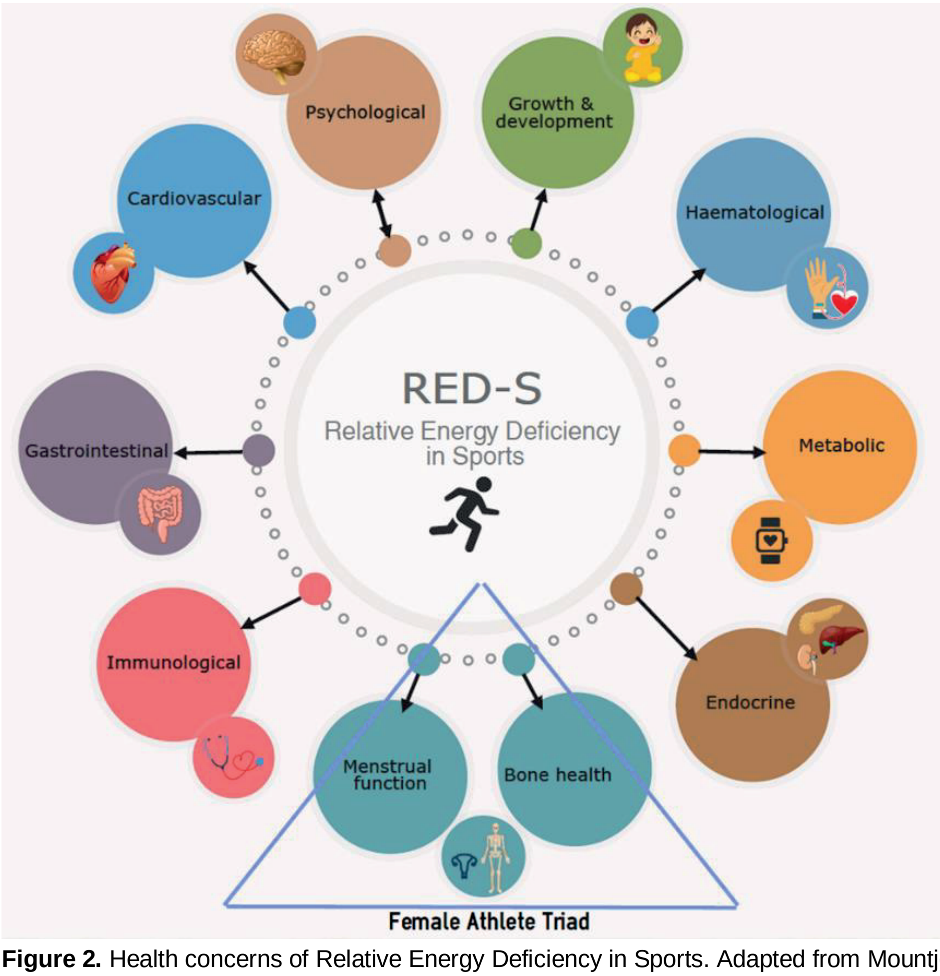


**Figure 2.** Health concerns of Relative Energy Deficiency in Sports. Adapted from Mountjoy et al.[30]

LEA affects the *endocrine* hormone levels of both female and male athletes. Most of the hormonal changes, for example, changes in appetite-regulating hormones, occur in order to reserve energy for the vital processes in the body.[30] Among men, significantly lower testosterone levels have been found among endurance athletes than among sedentary controls.[32] Reduced luteinizing hormone levels have also been found among male athletes with LEA.[30] Among female athletes, alterations in reproductive hormones affect the *menstrual function,* causing menstrual disturbances, which is one of the three components of the Female Athlete Triad. Typical menstrual disturbances among athletes are primary and secondary amenorrhea and oligomenorrhea.[31] Amenorrhea refers to the absence of menstrual cycles for more than three months and is called secondary amenorrhea if it begins after the age of menarche. Primary amenorrhea is defined as delay in the age of menarche (by age 15 years). Oligomenorrhea refers to menstrual cycles that occur at intervals over 35 days. The alterations in hormonal functions also affect the *growth and development* of adolescent athletes and the *bone health* of both sexes.[28] In amenorrhoeic and low testosterone athletes especially, sex hormone concentrations and bone mineral densities are significantly lower and bone injury risk is higher than among other athletes.

LEA also affects *metabolic* functions by reducing resting energy expenditure, especially in female endurance athletes.[30] In young female athletes LEA may also lead to *haematological* dysfunction, including low ferritin concentrations and iron deficiency anaemia. *Cardiovascular* changes, such as unfavourable lipid profiles and endothelial dysfunction may occur in amenorrhoeic athletes and athletes suffering from anorexia nervosa. A negative correlation between *gastrointestinal* symptoms, such as delayed gastric emptying and constipation, and LEA have been found in athletes. LEA can also affect *immunological* functions. For example, the likelihood of illnesses and upper respiratory symptoms may increase. *Psychological* problems may be caused by LEA or vice versa. A higher drive for thinness in particular typically precedes LEA. Thus, DE and EDs often go hand in hand with LEA.

It is important to improve the awareness and knowledge of RED-S among athletes, coaches, parents and members of sports organizations in order to prevent it.[30] Unfortunately, in the US for example, a minority of school nurses, coaches and other sports staff are able to identify the female athlete triad components or are even aware of it.[34] It is also typical for athletes to believe that irregular periods are normal for an active female.[30] The treatment of RED-S consists of systematic normalization of energy and nutrient intake, either by modifications to exercising patterns or nutrition practices. Simple nutrition education may help athletes with LEA resulting from unintentional under-eating. In more severe cases, such as LEA caused by EDs, psychological and pharmacological interventions as well as stricter exercising restrictions may be needed.

### 2.3.2 Eating disorders and disordered eating among athletes

EDs are mental illnesses that can have serious negative effects on athletes' health, performance and quality of life.[35–37] The mortality rates of EDs are the highest of any psychological illnesses.[37] DE patterns, such as restrictive eating behaviours; weight control; fasting or vomiting; disadvantageous attitudes related to eating, body shape and weight; binge eating; the use of laxatives or diuretics; and excessive training can gradually develop into more detrimental EDs.[36,37] These include anorexia nervosa, bulimia nervosa and EDs not otherwise specified (EDNOS) that all have their own diagnostic criteria.[36] EDs and DE can cause multiple symptoms in the body, such as general (e.g. weight loss), oral and throat (e.g. dental erosion), gastrointestinal (e.g. abdominal pain), endocrine (e.g. irregular menstruation), neuropsychiatric (e.g. depression), cardiorespiratory (e.g. chest pain), musculoskeletal (e.g. low bone mineral density and stress fractures), dermatological (e.g. hair loss), genitourinary, and renal (e.g. electrolyte disturbances) symptoms.[35] Among adolescent athletes, DE type of behaviour is especially risky due to the high energy demands of both growth and exercising, and due to their vulnerability to the psychological and physical consequences of DE and EDs.[16]

DE and EDs are more prevalent among adolescent elite athletes than non-athletes and more common among women than men.[38] However, the problem does also affect boys and men.[36] According to a Norwegian review[36], the prevalence of DE and EDs is 0–19% among male and 6–45% among female athletes. However, prevalence rates as high as 62% among female athletes and 33% among male athletes have been reported.[37] The prevalence of EDs and DE varies across different sports but also across different screening methods, for example, questionnaires versus clinical interviews which explains the large range in the percentages.[38] There are also limitations in the typical ED and DE screening methods that identify athletes at risk of developing an ED.[38]

EDs typically develop during adolescence and early adulthood.[38] This is also the same vulnerable period when body composition and shape change rapidly and when most elite athletic participation and competitions occur. However, the prevalence of ED and DE is slightly higher among adult elite athletes than among adolescent elite athletes. This is probably due to a longer duration of exposure to all sports-related factors that can increase weight concerns and unhealthy weight control behaviours.

ED rates are the highest in aesthetic sports, in sports with weight classes and in sports in which a low body mass is seen as advantageous, such as endurance sports.[35,37] Many endurance athletes aim for unrealistic body weight goals in the hopes of improving performance.[37] Among the risk sports for DE and EDs, inappropriate dietary and exercising strategies are commonly used to control body shape and weight in the hope that this will lead to better performance and body image. Sociocultural pressures outside sports also affect athletes, especially women's body image. Dissatisfaction with body image is one of the main predictors of DE. Due to sociocultural pressures, striving for thinness is common among women, as is striving for a muscular body among men. Athletes, coaches and parents should understand that body composition is just one of many contributors to an athlete's performance.[16] Pressuring an athlete to lose weight in order to improve performance is another important risk factor for the development of EDs. Due to increased pressures, adolescent athletes attending elite sports high schools may also be at increased risk of DE and the development of EDs.[38]

One way to prevent EDs is to educate athletes, coaches, parents and athletic staff members about body image and health and performance-related nutrition, regularly and early enough.[38] Athletes should be encouraged to seek help if they observe signs of abnormalities that can negatively affect their health and performance; for example, irregularities in their menstrual cycle.

## 2.4 Macronutrient requirements for young endurance athletes

The following chapters discuss the functions of different macronutrients in endurance sports. Table 1 presents the recommendations for macronutrient intake for endurance athletes. In sports nutrition, the requirements are typically expressed as grams per kilogram bodyweight instead of percentages of total energy intake (E%), in order to make the adequate nutrient intake more likely.[22] This is because grams are easier to conceptualize than percentages and because they represent absolute intake, whereas E% represents the relative proportion of the different macronutrients of total energy intake. Even when the energy intake remains below the need of the athlete, intakes presented as E% may be good; but the absolute intakes of nutrients may remain below the recommendations.

**Table 1.** Recommendations for macronutrient intakes for endurance athletes[22,26]

| Nutrient | Recommendation ($g \cdot kg^{-1} \cdot day^{-1}$) |
|---|---|
| **Carbohydrate** | |
| low-intensity training | 3–5 |
| moderate training (~1h·$day^{-1}$) | 5–7 |
| moderate to high intensity endurance training (1–3h·$day^{-1}$) | 6–10 |
| moderate to high intensity endurance training (>4–5h·$day^{-1}$) | 8–12 |
| | |
| **Fat** | ~1–2 |
| **Protein** | |
| high volume of intense training | 1.5–2 |

An interesting finding is that even though grams per kilogram bodyweight-based recommendations are generally used for athletes instead of E%, the recommendations for the general population, expressed as E%, are quite similar to the recommendations for athletes. As an example, if an endurance athlete consumes 6 $g \cdot kg^{-1} \cdot day^{-1}$ carbohydrates, 1 $g \cdot kg^{-1} \cdot day^{-1}$ fat and 1.5 $g \cdot kg^{-1} \cdot day^{-1}$ protein, the percentages of total energy intakes would be 62 E% carbohydrates, 23 E% fat and 15 E% protein. In the Nordic nutrition recommendations[39] for the general population the recommended percentages of total energy intakes are: 45–60 E% carbohydrates, 10–20 E% protein and 25–40 E% fat.

### 2.4.1 Carbohydrates

Carbohydrates play a significant role in enhancing performance and recovery. Over half of endurance athletes' energy should be obtained from carbohydrate sources. Carbohydrates are stored in the muscles and liver as glycogen. The carbohydrate for metabolism and subsequent energy production are derived from these glycogen stores and from exogenous carbohydrate that enters the blood stream when carbohydrates are ingested from foods or drinks.[17] Both total daily carbohydrate intake and the timing of their consumption have an effect on how fast glycogen stores are replenished.[16]

High carbohydrate availability is desirable in endurance sports. This refers to carbohydrate intake that is adequate in its quantity and timing for maintaining a sufficient supply of carbohydrate substrate for the muscles and central nervous system, thus contributing to optimal performance.[22] Sufficient carbohydrate availability and subsequent restoration of muscle and liver glycogen is also necessary for recovery from training and competitions. When an athlete has multiple exercises or competitions in a short period of time, special attention should be paid to adequate carbohydrate intake to ensure optimal recovery. In addition to decreased recovery rate, inadequate carbohydrate availability may easily lead to fatigue, decreased concentration and reduced immune function. Immune function decreases because the stress hormone level increases when carbohydrate intake is insufficient.[40] Inadequate consumption of carbohydrates may also lead to insufficient fibre intake, which is not beneficial for overall well-being.[41]

The type of sport and required amounts of training have a significant effect on carbohydrate recommendations (Table 1), which are lowest in low-intensity training or skill-based activity (3–5 $g \cdot kg^{-1} \cdot day^{-1}$) and highest in moderate to high intensity endurance training with very high training volume (>4–5 $h \cdot day^{-1}$) (8–12 $g \cdot kg^{-1} \cdot day^{-1}$).[22] The carbohydrate needs of an athlete may also vary depending on seasonal training programmes. The kind of carbohydrate intake needed in high intensity and volume endurance training is difficult to achieve if only complex carbohydrates with a low glycemic index, such as whole grain products, are preferred. In such cases, the use of carbohydrate juices or drinks or high carbohydrate supplements is also recommended.[26] It is also worth remembering that it is the total intake of carbohydrates, not only their glycemic index, that determines the effective replenishment of glycogen stores.

Carbohydrates consumed during exercise can enhance performance in multiple ways. During exercise lasting over two hours, the ingestion of carbohydrates prevents hypoglycaemia, saves muscle glycogen, delays fatigue, maintains blood glucose concentration, and keeps carbohydrate oxidation at a high level.[17,27,42] However, even shorter workouts can be enhanced with the ingestion of carbohydrates although the availability of muscle glycogen is not limited during such events.[22] The underlying mechanism has been hypothesized as being based on enhanced cerebral activity and thus differs significantly from the mechanism used in longer exercises.[42,43] The receptors in the oral cavity can detect carbohydrates or energy and activate higher brain regions.[42] Thus, in high-intensity training lasting approximately 45–75 minutes even carbohydrate mouth rinse may have a positive effect on performance as it activates the brain regions linked to the reward system, emotional behaviour, cognitive control and responses to interoceptors.[42,43] However, not all studies are unanimous on performance enhancement after mouth rinse.[43]

Endurance sports has several practices to ensure high carbohydrate availability. These guidelines are presented in Table 2. One should note that these recommendations are not based on a consensus meeting; they merely represent the conclusions of the authors of the specific article. In general, it is recommended that carbohydrates are ingested directly before and after exercise in order to ensure high carbohydrate availability.[22] To delay fatigue in sports lasting more than 60 minutes, adequate hydration and 30–60 $g \cdot h^{-1}$ carbohydrate intake are recommended. Gastrointestinal distress may occur if larger amounts of carbohydrates are consumed during strenuous long-lasting physical exercise and thus finding the most suitable individual refueling plan requires practice. In events lasting over 2.5 hours, liquid and fuel requirements are higher and are needed not only to ensure adequate carbohydrate availability but also to delay fatigue. During prolonged exercise, 60–90 $g \cdot h^{-1}$ carbohydrate intake is recommended.[42] Such amounts of carbohydrates can only be ingested if they are multiple transportable carbohydrates (combination of saccharides that rely on distinct transporters for intestinal absorption; e.g. some fructose in addition to glucose). Single transportable carbohydrates (e.g. glucose alone) can be oxidized at lower rates only, because the sodium-dependent glucose transporter SGLT1 becomes saturated at carbohydrate intakes around 60 $g \cdot h^{-1}$, thus limiting the absorption of glucose. Ingestion rates exceeding the absorption capacity may lead to accumulation of carbohydrates in the intestine and subsequent gastrointestinal distress.

**Table 2.** Acute fuelling strategies and practical tips to promote high carbohydrate availability and subsequent optimal performance, according to Burke et al.[22]

| Occasion | Explanation | Carbohydrate recommendation |
|---|---|---|
| General fuelling up | Preparation for <90 min exercise | 7–12 $g \cdot kg^{-1} \cdot day^{-1}$ |
| Carbohydrate loading | Preparation for >90 min sustained or intermittent exercise | 36–48 h of 10–12 $g \cdot kg^{-1} \cdot day^{-1}$ |
| Speedy refuelling | <8 h recovery between two fuel demanding training sessions | 1.0–1.2 $g \cdot kg^{-1} \cdot h^{-1}$ for first 4 h, then resume daily fuel needs |
| Pre-event fuelling | Before exercise >60 min | 1–4 $g \cdot kg^{-1}$ consumed 1–4 h before exercise |
| During short exercise | < 45 min | Not needed |
| During sustained high-intensity exercise | 45–75 min | Small amounts, mouth rinse |
| During endurance exercise | 60–150 min | 30–60 $g \cdot h^{-1}$ |
| During prolonged endurance exercise | > 150–180 min | Up to 90 $g \cdot h^{-1}$ |

The above-mentioned recommendations are for adult athletes and the studies they are based on have mostly examined men.[23] Even though the glycogen storage differs slightly at different phases of the menstrual cycle, women can still store glycogen at similar rates to men if they ingest adequate amounts of energy and carbohydrates.[22] Thus the carbohydrate recommendations for both sexes are the same.[19]

Even though the carbohydrate recommendations for youth are mostly based on findings among adults, some metabolic differences between adults and adolescents are known.[23] The glycolytic capacity of children and adolescents differs from that of adults and the nutrient oxidation routes are different. The blood lactate concentrations and capacity for lactate production are lower among children than adults and glycogenolytic capacity is also reduced. In addition, fat oxidation during exercise is higher among children than adults[23], and hence children rely more on oxidative metabolism.[19] Due to reductions in glycogen storage, children and adolescents may easily experience fatigue during prolonged exercise.[17] Children and adolescents may probably promote their performance by consuming carbohydrates during exercise, but research is not unanimous on whether the recommendations for adults also apply to them.[17,23] According to Petrie et al.[18], at least 50% of young athletes' total daily energy intake should be consumed as carbohydrates.

The carbohydrate intake of athletes is often below the guidelines.[25] Female endurance athletes in particular frequently have inadequate carbohydrate intake. On the other hand, potential under-reporting must always be considered when interpreting nutrient and energy intakes. The prevailing 'protein hype' and tendency to restrict carbohydrates among the general population and athletes may be one of the factors explaining insufficient carbohydrate intake.[41] Another factor is that endurance athletes tend to restrict their total energy intake in order to keep their body fat percentage as low as possible.[25] Professional nutrition counselling is recommended to help athletes understand the importance of sufficient energy and macronutrient intake for performance and overall health, and not only for controlling bodyweight.

### 2.4.2 Fats

Fat is needed for the provision of energy, essential fatty acids and the elements of cell membranes, for ensuring the absorption of fat-soluble vitamins (A, D, E, K) and carotenoids, for the synthesis of cholesterol and sex hormones and for the replenishment of the intramuscular triacylglycerol stores.[17,18,26,27] During adolescence, fat is also of great importance for healthy growth and maturation and for the synthesis of various hormones involved in these processes.[17] Fat is used as a fuel substrate either in the form of free fatty acids in plasma, intramuscular triglycerides or adipose tissue.[27] Endurance training enhances the oxidation rates of fatty acids and thus reduces reliance on carbohydrate stores.[16]

The fat intake recommendations for athletes are more or less the same as those for the general population.[27] According to dietary guidelines, approximately 20–30% of total energy should come from fats (20–35%[16,24] to 25–30%[17,18]). Of total energy intake, less than 10% should be obtained from saturated fats[27] and the diet should include sources of essential fatty acids.[24] The role of unsaturated fatty acids should always be emphasized to young athletes[17], and some guidelines even have separate recommendations for the intake of the two essential fatty acids: linoleic acid and linolenic acid.[18] For adolescent girls (14–18 y) 11 $g \cdot day^{-1}$ linoleic acid and 1.1 $g \cdot day^{-1}$ linolenic acid is recommended. For adolescent boys the recommendations are 16 $g \cdot day^{-1}$ and 1.6 $g \cdot day^{-1}$, respectively.

Compared to adults, children and adolescents are more efficient in substrate utilization: they can derive more energy from lipids at rest and at submaximal intensities.[17] In addition, they are more dependent on lipids for ATP production than adults. To ensure adequate carbohydrate intake, however, lipid intake greater than 30–35% of total energy is generally not recommended for young athletes.

Many athletes restrict their fat intake because they want to improve their body composition or to lose weight.[27] However, fat intake below 20% of energy intake is not recommended for athletes for long periods of time because it may lead to insufficient intake of fat-soluble vitamins and essential fatty acids. The growth and development of non-obese children can also be impaired if fat intake is limited.[18] If an athlete has excess body fat, dietary fat intake may be reduced. For athletes trying to lose weight, maintaining fat intake at 0.5–1 $g \cdot kg^{-1} \cdot day^{-1}$ is recommended.[26]

Some athletes favour low-carbohydrate, high-fat diets in the hope of better fat oxidation and benefits in performance.[27] However, this dietary strategy may actually reduce the metabolic capacity because it reduces carbohydrate availability and the capacity to use carbohydrates as an energy substrate during training. Thus, high amounts of carbohydrates rather than fats are recommended for competitive athletes prior to training and competition. The metabolic adaptations of such dietary strategies have not been studied among youth.[16,18]

### 2.4.3 Proteins

Adult athletes require high-quality protein for activating the protein synthesis pathway, for normal cellular functioning, and for providing amino acids for the synthesis, maintenance and repair of lean tissue.[16,17,27] These patterns are supported by consuming moderate amounts of protein regularly throughout the day and after training. High-quality protein refers to a protein source that contains all the essential amino acids, such as dairy protein. Sufficient, regular protein intake plays a significant role in aiding recovery processes.[26] Adolescents require slightly higher amounts of protein than adults.[16] During childhood and adolescence, protein is also needed for supporting growth and development. Proteins' primary function is not to serve as a substrate for energy production, but if the diet is low in energy, proteins can be used for this purpose.

The amino acid profile and the rates of digestion or absorption vary considerably between different protein sources and thus not all proteins are the same in their utilization.[26] Therefore, athletes should not only consume the recommended amounts of protein but also make sure that most of their protein sources are of high quality. Typically, chicken, fish, egg white and skimmed milk are referred to as the best quality protein sources.[26,44] For vegan adolescent athletes, it is important to consume enough protein from various sources in order to ensure adequate and diverse amino acid intake.[16]

The protein recommendations for adolescent athletes are based on those for adults.[16,18] The protein requirements of athletes are higher than those of the general population.[16] Intense training elevates protein needs to approximately twice that of the general recommended daily allowance.[18,26] Endurance training increases protein requirements because of increased protein oxidation.[24] Athletes with high volumes of intense endurance training need 1.5–2.0 $g \cdot kg^{-1} \cdot day^{-1}$ of protein to maintain the protein balance in the body.[26] For athletes with moderate amounts of intense training, the recommendation is 1.0–1.5 $g \cdot kg^{-1} \cdot day^{-1}$. According to many researchers, the recommendation for active adults (1.2–1.8 $g \cdot kg^{-1} \cdot day^{-1}$) is enough for youth athletes.[16,17] However, the activity level must again be taken into account and, therefore, young endurance athletes training intensively may benefit from the recommendation of 1.5–2.0 $g \cdot kg^{-1} \cdot day^{-1}$. In addition, some studies have highlighted the fact that research is still needed to confirm these recommendations because the possibility of growth spurts occurring during intensive training or a competition season has not been sufficiently been taken into account thus far.[18] If protein intake is insufficient, negative nitrogen balance may develop and lead to increased protein catabolism, slowed recovery and even muscle wasting.[26]

In addition to total intake, the timing of the protein consumption is important. The most recent protein recommendations also take the timing of protein intake into account.[27] After the main exercise session and then every three to five hours (or three to four hours[45]), a protein intake of 0.3 $g \cdot kg^{-1}$ is recommended in order to improve muscle adaptation to training.[27] This means that proteins should be consumed at regular intervals throughout the day.[16] When aiming to maximize skeletal muscle protein synthesis responses to training, approximately 20–40 grams of high quality protein is recommended immediately after any strength, high intensity or volume exercise.[16,45] This amount of protein corresponds to approximately 10 grams of essential amino acids.[27] Consuming higher doses (e.g. > 40g) of proteins per meal seems to provide no further benefits for training adaptation. In addition, endurance performance does not benefit from excess protein intake if carbohydrate intake is sufficient.[45]

Most athletes obtain sufficient amounts of protein from their diets.[18] This also applies to adolescent athletes.[16] Protein is found in many foods that athletes consume and therefore it is relatively easy to fulfil even elevated protein requirements through normal food. Young athletes should also always be encouraged to consume their proteins as whole foods.[17] Protein supplements are not generally needed and are mostly only recommended for specific occasions because of their convenience.

## 2.5 Micronutrient requirements of young endurance athletes

Vitamins and minerals, i.e. micronutrients, are needed for various normal physiological functions[17], for example, and they serve as cofactors in metabolic reactions and in the synthesis of body tissues, maintaining hydration balance, transmitting signals in nerve and muscle tissues, participating in immune function, and protecting the body against oxidative damage.[18,24] Adequate amounts of micronutrients are generally obtained with a balanced diet and sufficient energy intake.[17] Thus, it is recommended that children and adolescents obtain their micronutrients from food rather than from dietary supplements. In addition, if a diet is nutritionally adequate, micronutrient supplements do not provide any performance-enhancing properties.[24]

Exercise training may increase the need of vitamins and minerals.[24] Many micronutrients are needed in the metabolic pathways activated by training. Training may also lead to biochemical adaptations in muscles, thus increasing vitamin and mineral needs. In addition, training may increase micronutrient losses. However, athletes are more likely to obtain their dietary micronutrients than their non-athletic peers because of their higher total food consumption and subsequent total energy intake.[17]

Some micronutrients are of concern, especially if an athlete’s energy consumption is of a high level but their diet is low in energy and nutrients.[17] According to the latest sports nutrition recommendations for young athletes, the elevated risk of micronutrient deficiencies among adolescent endurance athletes mostly concerns vitamin D, and mostly depends on the place of residence and diet quality, and as well as the minerals calcium and iron.[4,5,16–18] The following chapters highlight these micronutrients.

### 2.5.1 Vitamin D

Many adolescent athletes are at risk of obtaining an insufficient amount of vitamin D from their diet.[4] A particular concern about vitamin D deficiency applies to athletes who are not exposed to sufficient amounts of ultraviolet (UV) B radiation from sunlight, either due to their place of residence or due to spending long periods of time indoors.[16,17] This applies especially to athletes living at higher latitudes where there is not enough UVB radiation during winter.[46] For example in the Nordic Countries (55° N–72° N )[39], due to a lack of UVB radiation, vitamin D cannot be produced in the skin for approximately six months of the year.[46] Therefore, for example in Finland, 7.5 µg of vitamin D supplementation is recommended all year round for all children and youth between 2 and 18 years.[47] In addition, in most Nordic countries, vegetable oil-based spreads and fat-free and low-fat milks are enriched with vitamin D.[39]

Sunlight exposure converts 7-dehydrocholesterol in the skin to previtamin $D_3$ which can then isomerize into vitamin $D_3$.[46] The metabolism of vitamin D takes place in the liver and kidneys, where it is converted into 25-hydroxyvitamin D and 1,25-dihydroxyvitamin D. The biologically active form of vitamin D is 1,25-dihydroxyvitamin D which is essential for regulating calcium and phosphate metabolism. This affects the maintenance of various metabolic functions and bone health. Vitamin D also enhances calcium absorption.[16] Vitamin D deficiency has multiple negative health consequences, such as an increased risk of various chronic diseases and impaired skeletal health.[46]

Depending on study methods and populations, vitamin D status and intake vary greatly among athletes.[46,48] As an example, the vitamin D intake of over 90% of adult and adolescent female athletes was recently reported to be below recommendations.[48] However, the food frequency questionnaire (FFQ) method used in the study in question may not have been as precise in assessing vitamin D intake as other methods, which also admittedly have limitations, mostly because some of the important sources of vitamin D, such as fish, may not be eaten daily. In addition, dietary recommendations for vitamin D vary across countries and are difficult to set because sunlight exposure is different in different populations.[17] Regardless of these complexities, many athletes may require vitamin D supplementation in order to sustain their optimal bone health and reduce the risk of stress fractures, for example.[4,17] In addition, some studies have also suggested that low vitamin D status among young athletes may impair their performance.[16] For athletes at risk of vitamin D deficiency, regular monitoring of vitamin D status is recommended.

### 2.5.2 Calcium

In addition to vitamin D, calcium is another key nutrient for the development of bones and the maintenance of bone health.[16] Calcium is also needed for growth, maintaining optimal blood calcium levels, regulating muscle contractions, nerve conductions and blood clotting.[24] During adolescence, bone growth and remodelling are significantly increased, which also increases calcium requirements.[16] Insufficient dietary intakes of calcium and vitamin D may lead to low bone mineral density and subsequent stress fractures.[24] In order to achieve optimal peak bone mass, adequate calcium intake is needed during childhood and adolescence.[18] In addition, the better the peak bone mass by the end of adolescence, the lower the risk of osteoporosis during adulthood.

Recommendations for adolescents' calcium intake vary by country. The recommendations for athletes do not differ from those for the general population.[16] Female adolescent athletes in particular often have a calcium intake that is considerably below recommendations.[4] However, adolescent male athletes have also been reported as having too low a calcium intake.[16] Desbrow et al.[16] have suggested that improving athletes' nutrition knowledge could be one way in which to increase their calcium intake, because athletes often have poor knowledge regarding nutrient sources.

For many adolescent athletes, dairy products are the main calcium sources. Milk consumption is often reduced during adolescence, which may reduce calcium intake.[17] Since calcium absorption requires sufficient vitamin D status, it is important to ensure that both micronutrients are present in adequate amounts in the diet. Special attention should be paid to adequate calcium intake if the energy intake of young athletes is low, dairy products are missing from their diet and the menstrual cycle of female athletes are irregular.[24] Skeletal health can be considerably impaired if the menstrual function is abnormal and the intake of calcium and vitamin D is also inadequate.[16]

### 2.5.3 Iron

Iron plays a central role in sports performance because, as part of the body's main iron-containing protein haemoglobin, it is an essential part of oxygen transport.[49,50] Scientific literature is quite unanimous in that athletes' suboptimal iron status can lead to impaired athletic performance and exercise capacity[51] and may have a negative effect on training adaptations[16], muscle metabolism, cognitive function[18] and the immune system.[24] Suboptimal iron status is associated with disturbances in oxygen transport, production of ATP and synthesis of DNA, all of which are further related to negative effects on endurance performance.[16]

Iron deficiency, with or without anaemia, is the most common nutrient deficiency in the world.[49] Iron deficiency anaemia can cause several health problems, such as fatigue, exercise-associated dyspnoea and neurological symptoms.[50] Iron deficiency is the result of blood loss, nutritional deficits, or both.[49] Iron deficiency anaemia is much more infrequent than plain iron depletion among both athletes and the general population, at approximately 0–3%.

Iron depletion can develop into more severe iron deficiency if the depletion is not detected early enough.[52] Biochemical indicators of the body's iron storages, transported iron and red blood cells are used to determine the extent of iron depletion. Iron deficiency typically occurs through four different stages: 1) moderate depletion of iron stores which causes no dysfunction, 2) severe depletion of iron stores but still no dysfunction, 3) iron deficiency, and 4) iron deficiency with dysfunctions and anaemia. To determinate iron deficiency, the levels of ferritin, total iron binding capacity, serum iron and complete blood count are typically estimated from blood samples.[49] Low serum ferritin concentration ($<15\ \mu g \cdot l^{-1}$) is considered the central variable for iron deficiency.[50] To ensure that iron deficiency does not develop, regular screening of athletes' iron status is recommended.[53]

Iron depletion without clinical symptoms is found among adolescent, endurance and female athletes more often than among the general population.[51] The eating habits of athletes, especially young female athletes, can be highly restrictive or unvaried (e.g. DE and veganism), which can lead to insufficient iron intake.[49] Women lose significant amounts of iron in menstrual blood, which explains why the recommendations for iron intake (Table 3) are higher for women than men.[16] Another main route for blood loss is through the gastrointestinal (GI) tract.[49] Athletes also possess other unique routes for blood loss. Endurance athletes may lose blood via the GI tract and less often the genitourinary tract after intense endurance training. Foot-strike haemolysis may also increase the risk of iron losses in some athletes, especially endurance runners. Iron may also be lost through sweat but most probably not in amounts that would increase the risk of iron deficiency.

Regardless of the athlete-specific routes for iron losses, some iron intake recommendations for athletes are the same as those for the general population.[16] Many researchers, on the other hand, recommend a greater intake of iron for endurance athletes because of their exercise-related increased iron losses.[27,54–57] The iron recommendations for endurance athletes are typically 30–70% greater than those for the general population.[57] The iron intake of the majority of male athletes, exceeds that of nutrition recommendations. On the other hand, female athletes are adviced to obtain sufficient amounts of iron from easily absorbable sources.[18] Foods rich in iron include, for example, red meat (heme iron), beans and cereal (nonheme iron).[17] It is recommended that foods rich in ascorbic acid (vitamin C) are consumed together with foods containing nonheme iron in order to increase iron absorption. Iron supplementation is recommended only for iron deficiency anaemia, and suboptimal iron stores and should always be guided and followed by a health professional.[16] Routine iron supplementation without medical indication is usually not recommended due to its potentially negative health effects (e.g. GI symptoms) and because supplementation in such situations has at most only minor benefits on performance.[49] In cases of iron deficiency anaemia, iron replacement therapy lasting several months is recommended in order to replenish iron stores.

Table 3 presents sport-specific and general recommendations for vitamin D, calcium and iron intake.

**Table 3.** Recommendations for vitamin D, calcium and iron intake for athletes and general Nordic population.

| **Micro-nutrient** | **American College of Sports Medicine position stand. (recommendation for athletes)**[24] | **Sports dietitians Australia Position Statement (recommendation for athletes)**[16] | **Nordic nutrition recommendations (general Nordic population)**[39] |
|---|---|---|---|
| Vitamin D | 5 $\mu g \cdot d^{-1}$ | 5 $\mu g \cdot d^{-1}$ | 10 $\mu g \cdot d^{-1}$ (youth and adults) |
| Calcium | 1500 $mg \cdot d^{-1}$ for athletes with disordered eating, amenorrhea or risk of early osteoporosis | 1300 $mg \cdot d^{-1}$ | 900 $mg \cdot d^{-1}$ (14–17 y)<br>800 $mg \cdot d^{-1}$ (18–30 y) |
| Iron | >18 $mg \cdot d^{-1}$ (women)<br>>8 $mg \cdot d^{-1}$ (men)<br>(requirements may increase by 70% among female endurance athletes) | 15 $mg \cdot d^{-1}$ (girls 14–18 y)<br>11 $mg \cdot d^{-1}$ (boys 14–18 y) | 15 $mg \cdot d^{-1}$ (girls over 14 y and women)<br>11 $mg \cdot d^{-1}$ (boys 14–17 y)<br>9 $mg \cdot d^{-1}$ (men 18–30 y) |

### 2.6 Hydration

Adequate hydration status is one of the main factors that affects athletic performance. For young athletes, it can be regarded as an even more important factor than for adults,[17] because children and adolescents have lower exercise tolerances in high temperatures and cannot regulate body temperature as effectively as adults.[16] This is explained by the following factors: 1) the surface area-to-body mass ratio of children is greater than that of adults, which leads to greater heat absorption from the environment on hot days but also greater heat losses on cold days[16], 2) the sweating capacity of children and adolescents is lower than that of adults and their ability to dissipate heat is reduced[16,17], and 3) children tend to produce more metabolic heat per unit mass during exercise than adults.[16] In addition to and in line with these factors, heat illness resulting from sports is more prevalent among youths than adults. Insufficient hydration status is one of the main aetiologic factors behind heat illness.

As well as the increased risk of heat illness, dehydration can easily lead to decreased performance, in the form of both increased fatigue and decreased perceived exertion during exercise.[17,18] Performance decreases because, due to dehydration, plasma volume declines, leading to increased cardiovascular strain.[17] This leads to reduced skin blood flow and, as a result, to a decline in the ability to dissipate heat to the environment. Unfortunately, according to review study by Smith et al.[17], most young athletes arrive for exercises in a hypohydrated state. Among athletes, regardless of their age, fluid losses greater than 2% of body weight should be avoided in order to maintain performance and work capacity.[16,18] Urine color and body weight can be used for estimating hydration status.[27]

Adequate hydration is also important for maintaining the electrolyte balance in the body. Increased sweating may cause a loss of sodium, calcium and iron through sweat.[2] In heavy endurance training, mineral balance problems such as, low plasma sodium concentrations may occur when sweat losses are great and are replaced with large amounts of water or other non-sodium liquid.[18] It is advisable to consume sports drinks including sodium during prolonged training, especially in hot environments. In addition to replacing the sodium lost in sweat, taking in sodium increases the drive to drink and may thus lead to better hydration status. For the same reason, the use of flavoured fluids is recommended, as athletes tend to consume these more during sports than non-flavoured fluids.[17] However, in the case of long endurance events the risk of overdrinking should always be taken into account. Drinking excessive volumes of low-sodium drinks during an event may result in excessively low plasma sodium concentrations, which can pose a health risk. Even cases of death have been reported due to hyponatremia in long endurance events in hot environments such as ultramarathons.

In order to ensure and maintain adequate hydration status, it is important for an athlete to drink enough throughout the day, not only during training and recovery.[2] The recommendations for fluids are usually given as millilitres (or cups) or as $ml \cdot kg^{-1}$.[2,5,17] The latter is especially suitable for young, growing athletes because it is not based on absolute volumes but takes into account the body mass of athletes.[17] According to the American College of Sports Medicine's (ACSM) position statement on nutrition and athletic performance[24] the goal of drinking is to prevent dehydration, i.e. a loss of > 2% of body weight. They claim that this can be achieved through the following steps:

**Before training**: At the latest four hours prior to exercise, an athlete should drink approximately 5–7 $ml \cdot kg^{-1}$ body weight.[24]

**During training**: The need to drink during exercise is mostly dependent on the environmental conditions and duration and intensity of the training. Sweat rates during exercise can vary between 0.3 and 2.4 $l \cdot h^{-1}$. Thus, the main intention of drinking during training is to avoid losses of > 2% of body weight to keep a proper hydration status. For high-intensity or long endurance training, beverages containing carbohydrates (maximum concentration 8%) are recommended to maintain a higher blood glucose level and to provide energy.[2,24] Carbohydrate concentrations greater than 8% are not recommended during exercise in order to avoid reduction in gastric emptying.[24]

**After training**: At least 450–675 ml of fluid for every 0.5 kg of body weight lost during training is recommended. Fluid and electrolyte losses can be replaced with sodium-containing rehydration drinks or milk, or with salty meals and water.[16,24]

The differences between carbohydrate containing sports drinks and caffeinated energy drinks should be taught to athletes already at a young age, because many young athletes do not seem to understand the difference between these two types of drink.[16]

## 2.7 Dietary supplements

The background information of the International Olympic Committee consensus statement on youth athletic development[4] notes that the use of dietary supplements, energy drinks and muscle enhancing behaviours, such as consuming large amounts of protein, is common among young athletes, especially among young males. Dietary supplements and nutritional ergogenic aids, i.e. substances that may enhance physical work or performance[2], are used because some adolescent athletes hope to enhance recovery and help avoid illnesses.[18] Protein supplements are commonly used in the hopes of enhancing performance, speed and strength, and are among the most popular supplements purchased by athletes.[17] This is probably due to the aggressive marketing of such supplements and the many misconceptions linked to proteins, such as protein supplements being needed to build muscles. A good strategy to reduce the unnecessary use of protein supplements is to make sure that athletes have sufficient knowledge about nutrition.

Many athletes also believe that vitamins provide energy or increase muscle strength, which may explain the use of dietary supplements.[2] Again, this may result from a lack of general and sports-related nutrition knowledge.[17] The pressure to perform as well as possible may also lead to supplement use, especially as the supplements are advertised and targeted towards youths and athletes in general.[4] Aiming for specific ideals of body image may also enhance supplement use.[16]

According to a review by Petrie et al.[18], no research-based evidence exists that supplement use among healthy and well-nourished, young or adult athletes promotes their growth, or that it increases lean body mass or athletic performance. The long-term effects of using dietary supplements also remain unstudied.[16] The advertising of supplements may be quite aggressive and create the impression that they are necessary. Based on the current scientific evidence, however, we can only conclude that it is not appropriate to encourage the use of dietary supplements as a means of improving the performance of adolescent athletes.[4]

An exception to the above are supplements such as iron and vitamin D, taken under appropriate guidance from health personnel and with medical indications.[16] However, as young athletes usually consume more food than non-athletes, they tend to obtain their vitamin and mineral needs from mere dietary sources, especially if their diet is healthy.[18] In addition, it is important to teach athletes the routines and benefits of healthy eating instead of a ‘win at all costs’ mentality, which can be connected to the use of dietary supplements and ergogenic aids.[16]

Finally, in addition to the above-mentioned, it should be noted that athletes who use dietary supplements may be at risk of violating antidoping rules because the supplements may contain substances prohibited in sports.[4,16]

## 2.8 Nutrition knowledge

Worsley[58] defines nutrition knowledge as knowledge of nutrients and nutrition, and as the ability to practically use this skill when making healthy food choices, for example. The relevance of specific nutrition domains may differ between nutritionists and other groups of people because nutritionists' scientific needs and interests may differ from others' interests. Worsley defines regular consumers' nutrition knowledge as 'a mile wide and a centimetre deep'. According to him, people may possess many facts about nutrition, but might not be able to connect them or to see their relevance in everyday life. This is understandable because interest and knowledge are interrelated, and people tend to have knowledge about things they are interested in.

Nutrition knowledge can also be defined as understanding the given topic, i.e. the individual's understanding of nutrition, including the ability to remember terminology related to food and nutrition, pieces of information and facts.[59] It can be measured using appropriate, validated questionnaires, and the indicators of knowledge can be reported as either numbers, percentages or scores.

Nutrition knowledge is among the factors that explain peoples' food choices.[15] Other factors are psychological (e.g. weight concerns), social (e.g. culture), economic (e.g. income); factors related to lifestyle and beliefs (e.g. motives for participating in sports); or determinants of food choice (e.g. taste). Sufficient practical skills (e.g. for cooking) are also needed for translating knowledge into healthier food intake.[60] According to the World Health Organization (WHO), health literacy means more than the ability to read pamphlets and make appointments. It consists of achieving 'a level of knowledge, personal skills and confidence to take action to improve personal and community health by changing personal lifestyles and living conditions'.[61] As both general and sport-specific nutrition knowledge are associated with athletes' food choices and subsequent nutrient intake[15], they may also have a significant impact on athletic performance.

The full potential of nutrition on athletic performance, recovery and health may be restricted because the nutrition knowledge of athletes and their coaches is often limited.[14,60,62–66] The main nutritional misbeliefs are typically related to energy density, dietary supplements and proteins.[13] Some athletes might not want to put their nutrition knowledge into practice because they doubt their knowledge and are more willing to use questionable strategies for placing performance above all else.[15] In general, coaches have shown to have better nutrition knowledge than athletes.[14] Athletes should have adequate nutrition knowledge in order to understand the importance of daily food choices and subsequent dietary intake for their athletic development and health.[14,15] Nutrition education is typically used for improving nutrition knowledge and compliance with dietary guidelines.[13,15]

In this thesis, nutrition knowledge refers to both general and sport-specific nutrition knowledge of nutrients and nutrition, and their significance for athletes.

### 2.8.1 Evaluating nutrition knowledge

Nutrition knowledge can be estimated using validated instruments designed for the target population.[67] Multiple review studies have concluded that further research using high-quality measures is needed in order to obtain more insight into sports nutrition knowledge among athletes and coaches.[13,68,69] The problem of many former surveys evaluating nutrition knowledge is that they have used inadequate or even non-validated nutrition knowledge instruments.[70] Focusing on only limited areas of nutrition has restricted the wider use of these questionnaires. Such instruments fail to assess the knowledge properly. Therefore, validated and updated measures that can draw a knowledge profile from the respondent should be developed to obtain a reliable assessment of nutrition knowledge.[13,69] When developing and choosing a suitable questionnaire, consideration should be given to health literacy and nutrition recommendations for optimal athletic performance.[13]

Several papers have provided examples of the typical steps for creating a valid nutrition knowledge questionnaire.[70–74] When developing a good knowledge questionnaire, special attention should be paid to at least face validity, pilot testing, content validity, test-retest validity, and internal consistency.[69] The use of an external expert panel in the validation process is important, especially for the content and construct of the items.[67]

Content validity refers to how well the items cover the subject of interest and also to the phrasing of the items.[67,75,76] Face validity refers to how well the items measure what is to be measured and how suitable the items are from the perspective of the expert panel.[76] Internal consistency means how well the items assess the same feature from different aspects, and the degree to which the items are interrelated.[67,76] To indicate this, tests such as Cronbach's α for continuous variables, or the Kuder-Richardson formula 20 for dichotomous variables are used. The value of α varies between 0 and 1, and a value of 0.7 or more is usually regarded as indicating acceptable reliability.[67,76] Using two groups known to have different knowledge levels is a common way to confirm the construct validity of the questionnaire, i.e. difference in knowledge.[67,72,75] A test with high construct validity measures what it claims to measure.[76] Test-rest reproducibility refers to how well the results from the same participants from two separate test sessions are in agreement.[67,76] The time interval between the tests should be long enough to prevent the respondents from remembering their answers but short enough to avoid actual changes in knowledge, for example two weeks to three months.[67] Test-retest reproducibility is considered significant if the correlation coefficient, i.e. Pearson's correlation, between the tests is > 0.7.[76]

An adequately validated questionnaire can also detect potential gaps in knowledge.[69] The information obtained from studies using such questionnaires can be used when, for example, planning targeted and effective nutrition education interventions.[77] By identifying the knowledge gaps, it is easier to target interventions towards groups needing more nutritional education, or towards specific dietary challenges such as inadequate carbohydrate intake.

Most of the nutrition knowledge instruments in use have been designed outside Europe. They have usually been directed towards university or college athletes and coaches in team sports.[64–66,78] Regardless of the sports discipline however, it is recommended that questions concerning general nutrition recommendations and knowledge are included in the surveys.[13] The number of items in a questionnaire should be reasonable enough for drawing conclusions but not too long for the respondent. The number of items in nutrition knowledge questionnaires typically varies between 20 and 100.[70–74]

### 2.8.2 Nutrition knowledge among athletes

The studies of athletes' and coaches' nutrition knowledge levels or interventions aiming to improve nutrition knowledge among them have mostly been accomplished outside the Nordic countries in adult team sport athletes. Table 4 presents studies of sports nutrition knowledge level and nutrition education interventions in which sports nutrition knowledge has been one of the topics of interest. Only studies (n = 20) from 2000–2019 of adolescent or youth athletes or coaches were included in the table presenting the studies similar to the populations of this thesis study. Studies conducted among adult, student or elite athletes were excluded even though some of the elite or student athletes may have been under the age of 20. Approximately 40 of the nutrition knowledge or nutrition education intervention studies were conducted among adult, student or elite athletes, mostly in Australia and the US. Trakman et al.[13] also noted in their systematic review that the majority of sports nutrition knowledge research has been carried out among

American college athletes, probably because it is relatively easy to recruit adequate numbers of athletes in these colleges.

**Table 4.** Novel (2000–2019) studies of nutrition knowledge level and nutrition education interventions in which nutrition knowledge was of interest, among coaches and adolescent/young athletes.

| Authors | Type of study* | Participants | Country | Sports |
|---|---|---|---|---|
| Argôlo et al. 2018[79] | 1 | athletes | Brazil | table tennis |
| Belski et al. 2018[80] | 2 | coaches | Australia | soccer/football |
| Cockburn et al. 2014[66] | 1 | coaches | United Kingdom | hockey/netball |
| Couture et al. 2015[81] | 1 | coaches | Canada | variety of sports |
| Cupisti et al. 2002[82] | 1 | athletes | Italy | variety of sports |
| Danaher and Curley 2014[83] | 1 | coaches | Canada | variety of sports |
| Doering et al. 2016[84] | 1 | athletes | Australia | triathlon |
| Jacob et al. 2016[85] | 1 | coaches | Canada | variety of sports |
| Juzwiak & Ancona-Lopez 2014[62] | 1 | coaches | Brazil | variety of sports |
| Kavouras et al. 2012[86] | 2 | athletes | Greece | volley-/basketball |
| Manore et al. 2017[87] | 1 | athletes | US | soccer/football |
| Nascimento et al. 2016[88] | 2 | athletes | Brazil | variety of sports |
| Patton-Lopez et al. 2018[89] | 2 | athletes | US | soccer/football |
| Philippou et al. 2016[90] | 2 | athletes | Cyprus | swimming |
| Smith-Rockwell et al. 2001[91] | 1 | coaches | US | variety of sports |
| Torres-McGehee et al. 2012[14] | 1 | coaches | US | variety of sports |
| Walsh et al. 2011[92] | 1 | athletes | Ireland | rugby |
| Webb and Beckford. 2014[93] | 1 | athletes | Trinidad & Tobago | swimming |
| Whitehouse and Lawlis 2017[94] | 1 | athletes | Australia | variety of sports |
| Zinn et al. 2006[78] | 1 | coaches | New Zealand | rugby |

*Number 1 refers to studies of nutrition knowledge level and number 2 to nutrition education interventions in which nutrition knowledge was of interest

Some review studies conclude that the level of athletes' nutrition knowledge varies widely.[13,68,69] Heaney et al.[68] correlated nutrition knowledge and the nutritional quality of food choices of athletes in a systematic review of 29 studies. Their main result was that athletes' nutrition knowledge was better than that of non-athletes, but poorer than that of nutrition students. Women had significantly better knowledge than men. They also had a weak but positive association between nutrition knowledge and dietary intake. However, the variability in the assessment methods in nutrition knowledge and dietary intake, as well as the quality of the study tools, was wide. In their systematic review of 36 studies, Trakman et al.[13] reported a possible association between gender, education level, athletic level and nutritional knowledge. The nutrition knowledge scores they reviewed varied from

33.2% (SD: 12.3) (Iranian basketball and football players) to 81.8% (SD not reported; college athletes from the US). They also reported that the heterogeneity and variation in the methods used made it difficult to compare the results of different studies.

Older athletes tend to have better nutrition knowledge scores than younger athletes.[60,95] This might be due to nutritional issues appearing less relevant to younger athletes.[60] Less education years may also lead to lower ability to understand nutritional issues. Athletes competing at the elite level (e.g. international vs national level) typically have better nutrition knowledge than non-elite athletes[13,15,60] which reflects the better overall support and access to nutrition resources of elite athletes.[13] An Australian study observed no significant differences between individual or team sport athletes' nutrition knowledge at the national, junior or open international level.[60]

According to two reviews, the reported dietary intakes were healthier among athletes with better nutrition knowledge.[68,69] In these cases, 'healthier' was associated with a greater intake of vegetables and fruits. The athletes' main misbeliefs and gaps in nutrition knowledge were related to energy density, dietary supplements and proteins[13], both as pre-competition meals, and fluids and hydration.[2]

### 2.8.3 Nutrition knowledge among coaches

In addition to parents, social media, health store personnel, magazines, and other athletes, coaches are among the most important sources of nutrition knowledge for athletes.[2,15] Due to the close relationship between coaches and athletes, coaches' attitudes and behaviours may notably influence athletes' physical and psychological health.[96] Thus, it is important that coaches have adequate, up-to-date knowledge of nutrition, a readiness to protect athletes from inappropriate nutritional information, and sufficient skills for providing nutritional advice.[95]

Coaches appear to have better nutrition knowledge than athletes.[13,14] In the review by Trakman et al.[13], the nutrition knowledge scores of coaches varied from 55% (SD not reported; coaches of various sports in the US) to 81.6% (SD: 10.3; college coaches of various sports in the US). In all studies that assessed the nutrition knowledge of both athletes and coaches, the coaches obtained better results. The coaches who regarded their nutrition knowledge as very good obtained higher total knowledge scores than the coaches who regarded their knowledge as only satisfactory.[66]

Coaches also have similar misunderstandings related to nutrition to those of athletes. In addition, it has been reported that coaches tend to overvalue proteins, low-fat diets and food myths.[62] Coaches have been reported as the main initiator of athletes' protein supplement use and also athletes' main source of information regarding dietary supplements. Therefore it is of great importance that coaches' knowledge regarding dietary supplements is not biased.[94]

### 2.8.4 Consequences of limited nutrition knowledge

Reaching a high athletic performance and speedy recovery can be difficult if an athlete's nutrition knowledge is considerably limited. The urge to win, misunderstandings and biased attitudes towards nutrition due to a lack of knowledge can lead to unnecessary dietary manipulations and even to severe consequences such as EDs.[38] An example of a less severe but unnecessary consequence resulting from limited knowledge is the overemphasized use of expensive dietary supplements.[2] Athletes may spend a great deal of money on dietary supplements[2], especially if their nutrition information is derived from magazines, family members or coaches[17] or from commercially driven nutritional messages.[16]

It is important that young athletes learn the basics about healthy nutrition and general guidelines for sports nutrition already at the beginning of their athletic careers. For example, learning the basics about the quality and quantity of different fat sources and emphasizing the role of unsaturated fatty acids is important because the origins of cardiovascular diseases begin at an early age.[17] Therefore, sufficient nutrition knowledge and healthy eating behaviours at a young age may help prevent various chronic, progressive lifestyle diseases and obesity in adulthood.

An association between limitations in nutrition knowledge, Female Athlete Triad and DE has been observed among female endurance athletes.[97] Nutrition education interventions have been shown to help prevent EDs.[98] It has also been found that not only coaches' nutritional knowledge can be significantly improved by an intervention focusing on healthy diet, eating habits and EDs, but that their awareness and engagement in preventing ED can be improved at the same time, and as a result, the prevalence of DE among athletes can also be reduced.[99]

## 2.9. Improving nutrition knowledge

### 2.9.1 Behavioural change and motivation in education

In order to achieve lasting dietary changes, it is advisable to combine traditional nutrition education with behaviour change strategies and teaching the practical skills needed to select a desirable diet.[69,100,101] The benefits of diet changes, the real role of food in one's life, and especially the fact that a change is possible should be made attractive to the individual.[101] Simply providing information and increasing knowledge does not always turn into a certain behaviour if the intention to perform the behaviour is lacking.[102] Some nutrition interventions for athletes have been based on behavioural change theories.[103,104] Abood et al.[103] designed their education programme to emphasize athletes' self-efficacy by using the Social Cognitive Theory (SCT)[105] as the conceptual framework for the education. Self-efficacy[105] was emphasized by several in-class activities such as calculating one's energy requirements and observing other athletes' positive dietary behaviour. During the intervention, the athletes were encouraged to apply the information they learned. Buffington et al.[104] used Cognitive Behavioural Therapy (CBT) based on the COPE (Creation Opportunities to Personal Empowerment) programme in their intervention. Their programme taught participants problem-solving and coping skills during separate sessions and as homework. As a result, they observed an association between beneficial body composition change and nutrition knowledge. It is also worth noting that several theories have partly overlapping constructs and that no valid criteria exist to justify preferring one theory over another.[106] According to Davis et al.[106] researchers tend, therefore, to choose common or favoured theories regardless of their suitability in the study population or setting in question.

Self-Determination Theory (SDT) has also been used in interventions aiming to increase motivation and behavioural changes. This theory is used to explain the role of humans' inner resources for personality development and behavioural change.[107] According to SDT, three basic psychological needs – autonomy, competence and relatedness – should be satisfied in order to enhance self-motivation and mental health. Expanding feelings of autonomy is a good way to achieve intrinsic motivation.[108] Changes in nutritional behaviour are more likely to be permanent if they are backed by autonomous motivation.[109]

Suitable operation models from school life can also be utilized when planning and giving education sessions to athletes. The older the students are, the more important the feeling of autonomy is for them to make decisions. It has been shown that if teachers support students' autonomy in decision-making, stronger intrinsic motivation is created than if they apply control.[110] When an authority respects the choices and perspectives of student and encourages them in decision-making, the support of autonomy is evident.[111] Meaningful learning can be used as a theoretical framework for effective education. It starts from the motivation process[112] and is followed by these steps: orientating, internalizing, application and use, and evaluation and control.[113] These steps are described briefly below. Figure 3 summarizes the meaningful learning process.

The motivation process is the starting point of meaningful learning and originates from real life problems.[112] When these problems are seen as interesting educational challenges, meaningful learning processes can begin. Such motivation is highly intrinsic when aiming to achieve a certain goal. The formation of an orientation basis can be regarded as the most important step in a meaningful learning process. During this phase, the individual creates a model to solve and explain problems that have previously arisen. Internalization is the step of finding an internal model of the orientation basis to make it concrete. An internal model that can be used in different situations aims at gradually decreasing the need for any external instruments. During the application and use step, the previously created explanation model is practiced in order to adapt it as a suitable instrument for solving the new, concrete tasks. This can be regarded as the real internalization, as internalizing seldom takes place in a short period of time. The models strengthened during this step can also be used as such in similar situations in the future or they can be developed further. The idea of evaluation and control is to summarize the learning process: what has been understood, what can be adapted in future learning situations, and how to act in the future to improve learning.

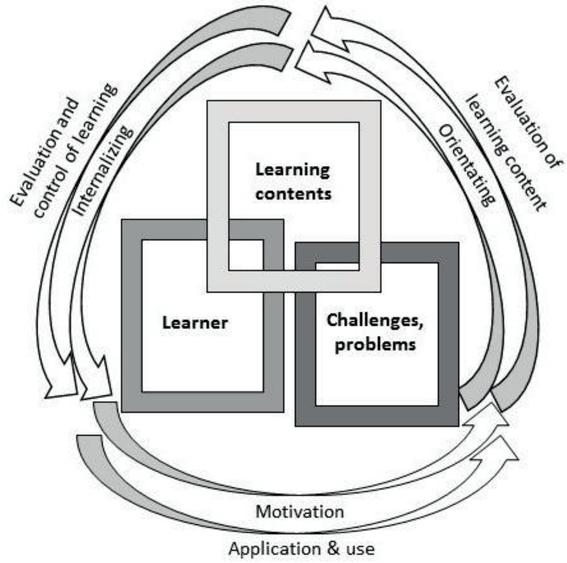


**Figure 3.** The meaningful learning process. Figure inspired by Autio[112], Engeström[113] and Davydov's concept of developmental teaching.[114]

### 2.9.2 Nutrition interventions among athletes

Nutrition education interventions aim to influence athletes' nutrition knowledge and dietary intake.[68] Table 5 presents details on previous nutrition education interventions on athletes and coaches, published in 2000–2019. The duration and content of these interventions have varied greatly. Typically, they have lasted between two and eight months.[85,88,90,100,103,104,115–117] Education has been provided either in group sessions, mainly as lectures[103,104,117] or in individual face-to-face counselling sessions.[88,100,115] Nutrition knowledge and other variables (e.g. food behaviour, motivation, body composition and performance) have been measured pre- and post-intervention using, for example questionnaires and food diaries.

Athletes' nutrition knowledge has significantly improved in multiple intervention studies.[88–90,100,103,104,115–118] In addition to improved nutrition knowledge, other positive outcomes have also been reported: increased self-efficacy, improved hydration status[86], overall number of positive dietary changes and improved body composition.[100,103,104] Increased levels of hormones affecting the menstrual cycle[116] as well as enhanced athletic performance[117] have also been reported. The nutrition knowledge of coaches and the accuracy of nutrition recommendations provided by coaches have also improved.[85] Multiple dietary concerns have been left to be considered in future interventions. One of these is to educate athletes about appropriate energy requirements and sufficient carbohydrate consumption.[115]

Sustaining athletic performance with too low an energy intake is not possible and, therefore, education regarding nutrients, the negative effects of skipping meals and tips for competition days and eating on the road are needed.[103,115]

One of the limitations of nutrition education interventions is that they may require too much time and energy from the viewpoint of busy athletes and coaches.[117] However, it is of interest that Rossi et al.[117] demonstrated that nutritional status, body composition and shuttle run performance could be significantly improved with a single 90-minute nutrition lecture, together with some short follow-up sessions. Similarly, a half-day nutrition workshop and guided supermarket tour significantly increased nutrition knowledge.[90] In contrast, an intervention consisting of only a single, three-topic nutrition education session resulted in only slight improvements in athletes' diet quality.[119] That particular study did not measure the nutrition knowledge of the athletes. The authors suggested that continuous nutrition education throughout the season could have been key for changing dietary behaviour.

**Table 5.** Main outcomes from earlier nutrition education interventions among athletes (16 studies) and coaches (1 study) from the 2000s. Review articles, interventions with a very small amount of participants (e.g. 2), interventions in which the participants were not athletes or coaches, or interventions concentrating purely on preventing EDs, DE or restrictive eating behaviour, and interventions concentrating on only body composition and sports performance were excluded.

| Authors | Athletes (n) | Intervention | Duration | Control group | Main results |
|---|---|---|---|---|---|
| Abood et al. 2004[103] | Female soccer players (n=15) | 8x1-hour education sessions | 2 months | Female swimmers (n=15) | Significant increase in nutrition knowledge, self-efficacy and overall number of positive dietary changes in IG |
| Anderson 2010[120] | Female college volleyball players (n=8) | Individual feedback for the whole team on 3-day food records 3 times during second season | 2 years | - | Dietary feedback resulted in significant increases in intakes of protein, vitamin C and calcium |
| Beggs et al. 2016[100] | Female rowers (n=7) | 8x35 min individual sport nutrition counselling sessions & 8 co-active life coaching sessions | 3 months | - | Significant increase in nutrition knowledge, non-significant reduction in athletes' fat mass and waist circumference, positive reporting of impacts of intervention |
| Buffington et al. 2016[104] | Female athletes from US Air Force Academy (n=153) | 10 short education sessions (via own computer) + homework;<br>three experimental groups | 2.5 months | 1/3 of recruited athletes | Significant improvement in knowledge of energy balance<br>Significant reduction in percentage of body fat in IG |
| Cleary et al. 2012[121] | Female adolescent elite volleyball players (n=36) | 4 observational periods (including 1 education session) | 1 month | - | Education session alone did not change hydration behaviours<br>Individualized hydration protocols improved hydration |
| Coccia et al. 2018[118] | Student athletes from swimming, baseball & softball teams (n=50) | Social media intervention using Twitter | 1.5 months | - | Significant increase in nutrition knowledge, significant decrease in BMI, reduced fat intake |
| Jacob et al. 2016[85] | High school coaches from various sports (n=41) | 2 x 90-min theory-based sessions. The IG also received an algorithm to summarize sports nutrition guidelines and help giving advice | Approx. 2 months | n=26 of recruited coaches | Coaches in the IG provided more nutrition recommendations and of improved accuracy.<br>Knowledge significantly increased in both groups, but was maintained only in IG during follow-up |
| Kavouras et al. 2012[86] | Child athletes (n=61) | 1-hour lecture on hydration, urine colour chart in all bathrooms of camp, improved water accessibility | 5 days | Child athletes (n=31) | Significantly improved hydration status and performance in endurance run in IG |
| Lagowska et al. 2014[116] | Female rowers, swimmers, & triathlonists (n=31) | Dietary counselling session + individual diet for athletes | 3 months | - | Significant increase in energy intake, energy availability and energy balance. Significant rise in LH concentrations and LH to FSH ratio. No changes in BMI or body composition, no restoration of menstrual cyclicity |

| | | | | | |
|---|---|---|---|---|---|
| Molina-López et al. 2013[119] | Male handball players (n=14) | Single, 3-phase session of nutrition education | 4 months | - | Significant increase in total energy and macronutrient intakes but no significant changes in macronutrient or micronutrient intakes after adjustment for energy intake |
| Nascimento et al. 2016[88] | Adult and adolescent athletes (n=32) | 4 individual nutrition counselling sessions + 1 healthy eating lecture | 6 months | - | Increase in lean body mass and nutritional knowledge in both groups, beneficial changes in eating behaviour (e.g. more vegetables and fruits), some healthy changes only in adolescent group (e.g. healthier meal frequency) |
| Patton-Lopez et al. 2018[89] | High school soccer players (n=153) | Health assessments, face-to-face sports nutrition lessons, experiential learning & team-building workshops | 2 years | High school soccer players (n=64) | IG increased knowledge scores significantly by 10% and participants were 3 times more likely to report trying to eat for performance |
| Philippou et al. 2016[90] | Female and male swimmers (n=34) + their parents (n=22) | Half-day nutrition education workshop | 1.5 months | - | Significant increase in nutrition knowledge and adherence to Mediterranean diet. Trend for a lower knowledge score post-intervention in swimmers whose parents did not participate in intervention |
| Rastmanesh et al. 2007[122] | Adult athletes with physical disabilities (n=42) | Nutrition education consisting of booklet with food guide pyramid, simple concepts about nutrition and weight loss, and 4 x 3-hour courses | ~1 month | Adult athletes with physical disabilities (n=30) | Improved nutritional knowledge and interest in nutrition in IG |
| Rossi et al. 2017[117] | Male baseball players (n=15) | Dietary counselling session in beginning + short follow-up every three weeks | 3 months | Male baseball players (n=15) | Nutrition knowledge increased; energy, fat and protein intakes differed from pre-intervention; body fat percentage decreased; shuttle run performance improved significantly in IG. No significant interactions in jumps and squats |
| Simpson et al. 2017[123] | Elite male field hockey players (n=17) | Athletes logged images of their meals 3 days/week and received individualized feedback | 1.5 months | - | Nutrition knowledge increased moderately during intervention. Athletes reported highly positive experience of application use with > 80% trying to make positive changes in dietary behaviours based on in-app education |
| Valliant et al. 2012[115] | Female volleyball players (n=11) | Individualized dietary education after completion of 3-day food records once/ month | 4 months | - | Significant increase in sports nutrition knowledge and significant increases in total energy, carbohydrate and protein intakes |

Abbreviations: IG=intervention group, LH=luteinizing hormone, FSH=follicle-stimulating hormone, BMI=body mass index

### 2.9.3 Use of mobile applications and other modern technologies in nutrition interventions

In modern nutrition interventions, the use of mobile applications (apps) is increasing and replacing or complementing the use of traditional 'low tech' methods, such as food diaries using pen and paper, especially among younger participants who prefer the new technology.[124–126] A popular technology for dietary assessment is an image-assisted food record.[124] This is any method in which meal photographs are used as the main record of dietary intake or as additional material to traditional text-based methods. Compared to traditional methods, image-assisted food recording is regarded as more convenient and easier to implement in daily routines.[127] It can also make education interventions more convenient and time-efficient. Using photographs can improve the accuracy of self-reporting by adding more details compared to only written descriptions of meals, reduce underreporting, and make interventions more cost-effective.

The growing number of mobile devices and diet apps can provide nutrition specialists with new tools for assessing and tracking dietary intake. These mobile health (mHealth) technologies can also increase patient engagement and promise to improve results and to reduce healthcare costs.[128] In food apps, food consumption inputs can be stored as, for example, general inputs, labelled food products, barcodes, food images, recipes, restaurant dishes, or nutrient input.[129] Some diet apps can convert the recording of food data into nutrient intake and compare it with nutrition goals set for the individual.[125] In some apps, the information can be shared with a nutrition specialist in real time without the need for face-to-face contacts.[125,130] However, the majority of the publicly available food consumption apps do not provide any personal feedback.[129] Tracking dietary intake can also be a benefit in itself as it promotes athletes' compliance with nutrition recommendations.[125] Even though most diet apps are designed for weight management and only some are especially for sports nutrition, many sports nutrition specialists find these apps useful when working with athletes.

Several mobile apps have also been used to facilitate healthy eating. Taking and looking at meal pictures seems to enable observation of what, when and how much one eats in reality. This implies that nutrition interventions can be designed, instead of focusing on energy intake or other nutrient details, to emphasize the composition of and satisfaction with a meal.[131] Apps may also be useful for increasing nutrition knowledge.[132]

A selection of reliable and validated apps is crucial, as their quality varies, characteristics and extracted information are poorly documented, and they often lack any accepted underlying behavioural theory.[133–135] As an example, many weight-loss mobile apps do not include any important behavioural strategies in weight management, such as strategies to improve problem-solving skills and manage stress.[133] The same is true for most physical activity tracking apps.[134] A possible reason for the absence of behavioural strategies is that app developers value user-friendliness and engagement more. There is no reason not to apply technology to facilitate attitude and behaviour change through persuasion and socialness. These aspects have already been exploited in some social-media and game-based nutrition interventions targeted at young adults.[132]

Recently, for instance, a study of elite male field hockey players (n = 17, age = 18–20) from New Zealand used a mobile app to increase athletes' nutrition knowledge and promote their nutrition behaviours.[123] The athletes logged images of their meals three days per week over six weeks. They received weekly nutrition education fact-sheets and videos through the application. As a result, the nutrition knowledge of the athletes increased moderately, and they reported that they tried to make positive changes in their dietary behaviours based on what they had learned through the app. The participants were able to view their teammates' meal images through the app, which they also believed to have had an effect on their own food behaviour. The application use was rated as a highly positive experience and all the participants preferred the app over traditional dietary analysis methods. The behavioural change-promoting feature of the app in this study was based on SCT.[105] The athletes were able to self-reflect on their behavior, the aim of which was to increase their feelings of self-efficacy. The social media function, the utilization of peer-support, the professional feedback from a nutritionist and the utilization of a former hockey captain as role model in the educational videos were also regarded as having an impact on athletes' nutrition knowledge and dietary behaviours.

According to Nour et al.[132], a problematic feature in many social media or game-based nutrition education interventions targeting young adults is that the overall quality of these studies has been low. The tools used in the studies aiming to increase nutrition knowledge have mostly been non-validated and the use of long-term measures of behavioural outcomes and weight, for example, has been limited. In some cases, validation has only been carried out in specific groups such as older women which may reduce the tools' usability among young or male populations.[136] It should also be taken into account that most diet apps have been designed for Americans, which may reduce their usability in other regions. As mentioned earlier, the fact that most dietary-recording apps are designed for weight management may reduce their validity in research settings as they provide continuous feedback on the amounts of consumed energy or nutrients and thus interfere with the dietary behaviour of the users.[136] Some dietary recording apps have also been validated for research purposes (e.g. My Meal Mate, electronic Dietary Intake Assessment (eDIA), Easy Diet Diary and Eat and Track (EaT)).

As mobile apps and other modern technologies for nutrition promotion have only been used for a few years, they can be regarded as being in their infancy.[132] In the course of time, the amount of validated apps and other modern technologies, and their use in nutrition interventions, is likely to increase.

# 3 Aims of the thesis

The nutrition knowledge of athletes and coaches is often limited. Misunderstandings and gaps in knowledge may prevent athletes from benefitting from the full potential of nutrition for performance, recovery and health. Nutrition knowledge may, however, be improved through education interventions. Improvements in nutrition knowledge may lead to other positive outcomes, such as healthier dietary intakes.

Most of the research on the nutrition knowledge of athletes and coaches has been conducted outside the Nordic countries, among young adult team sport athletes. Given the importance of nutrition in endurance sports, the purpose of this thesis is to investigate the nutrition knowledge and nutritional skills of young (16–20 years) Finnish endurance athletes. Its specific aims were:

I: To develop a reliable, valid questionnaire to assess the nutrition knowledge of young endurance athletes and their coaches.

II: To describe the nutrition knowledge of young Finnish endurance athletes and their coaches.

III: To determine whether the nutrition knowledge and dietary intake of young Finnish endurance athletes can be improved through a nutrition education intervention and whether a mobile food application can enhance their learning.

# 4 Participants and methods

This study used data from three different but interconnected sub-studies. The design of the thesis and the names of the sub-studies are presented in Figure 4. Study I aimed to create and validate a nutrition knowledge questionnaire (Appendix 1) to evaluate this knowledge among young Finnish endurance athletes and their coaches. In Study II, data on the nutrition knowledge of 312 athletes and 94 coaches were collected using the questionnaire. The results of Study II were then used to design Study III, a nutrition education intervention aiming to improve the nutrition knowledge and dietary behaviour of young athletes. The intervention compared the effects of participatory nutrition sessions alone to a combination of the same sessions and a mobile app. The subsequent chapters describe this in detail. The studies were reviewed by the University of Helsinki Ethical Review Board, and they followed the ethical principles of research in the humanities and social and behavioural sciences, issued by the Finnish Advisory Board on Research Integrity.

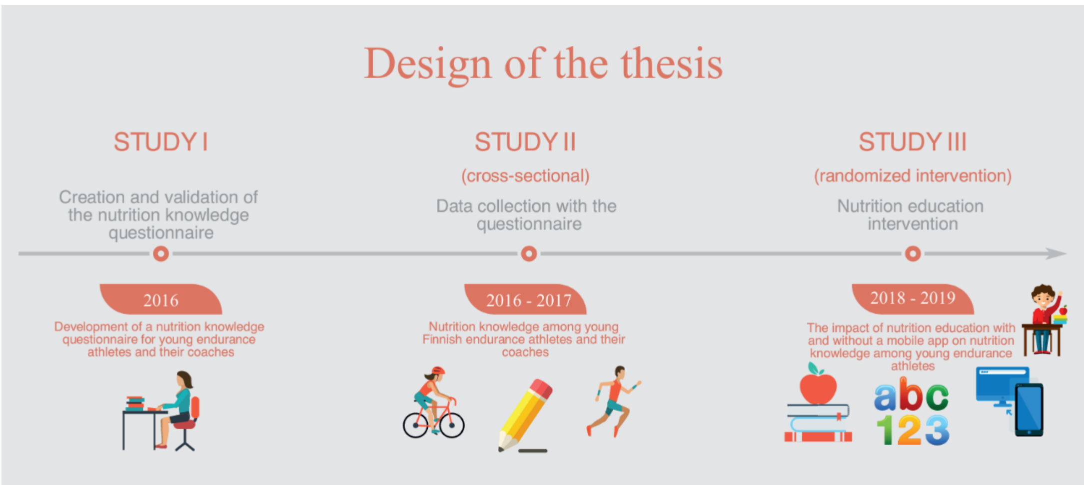


**Figure 4.** Design of the thesis

## 4.1 Participants

Table 6 presents the participants of Studies I–III. In all the studies, most of the participants were cross-country skiers (Study I: all athletes and coaches; Study II: 36% of athletes and 56% of coaches; Study III: 42% of athletes). Most of the study participants were recruited via e-mail either directly or via their coaches. Some participants of Study II were also recruited on training camps or at their sports high schools. The participants were recruited from major sports clubs, sports high schools, sports academies, the Finnish Military Sport Federation, and the elite training groups of the Finnish Ski, Biathlon, Orienteering and Triathlon Associations, and the Finnish Athletics Federation. All the athletes competed on at least a national level. The study participants completed an informed consent form.

The inclusion criteria (Studies II and III) included participants within the age range of 16–20 years whose main sport was an endurance sport. In Study II, 21 athletes were excluded as they were not 16–20 years old. In Study III, 62 of the 79 participants completed all the nutrition knowledge questionnaires and were included in the nutrition knowledge analyses. Sixty-seven completed both food diaries and were thus included in the nutrient intake analyses.

**Table 6.** Thesis study participants.

| Study | Participants | n | Age (±SD) | Women (%) | Recruitment | Time |
|---|---|---|---|---|---|---|
| I | Cross-country skiers | 16 | 17.0±1.8 | 31 | Via e-mail from local skiing club | 2016 |
| | Cross-country skiing coaches | 13 | 41.3±10.0 | 38 | | |
| | Master's students in nutrition | 20 | - | - | Via e-mail from University of Helsinki | |
| | Master's students in humanities | 22 | - | - | | |
| II | Endurance athletes | 312 | 17.9±1.2 | 50 | Via e-mail from different sports high schools, major sports clubs, and the elite training groups of the Finnish Ski, Biathlon, Orienteering and Triathlon Associations and the Finnish Athletics Federation, or at training camps or high schools | 2016–2017 |
| | Endurance coaches | 94 | 44.3±12.3 | 27 | | |
| III | Endurance athletes | 79 | 18.0±1.4 | 44 | Via endurance sport coaches of two Finnish sports academies, defence forces and two sports clubs | 2018–2019 |

The number of participants recruited for Study III was based on the power size calculations, based in turn on the results from Study II. The interventions were conducted in five separate locations between April 2018 and February 2019 (Figure 5). The interventions for the winter sport athletes took place during the spring, and those for the summer sport athletes during the autumn–winter, in order to avoid having education sessions during the respective competition seasons.


**Figure 5.** Locations of interventions in Study III. Participants of the interventions (*) in Kajaani, Vuokatti and Espoo were mostly winter sport athletes.

## 4.2 Study designs

### 4.2.1 Creating and validating a nutrition knowledge questionnaire (Study I)

Figure 6 presents the five major steps of the questionnaire development process, which are briefly discussed below and in more detail in Study I. We followed the same extensive validation criteria[67] for creating nutrition knowledge questionnaires as used in previously published study designs.[72,74] An external panel of six professional sport nutrition experts was consulted during each of the major steps. Reliability and validity were evaluated as test-retest reliability, internal consistency reliability, content validity, face validity, and construct validity. Contrary to common procedure, this chapter combines the methods and results sections, as this makes it easier to follow the development process.

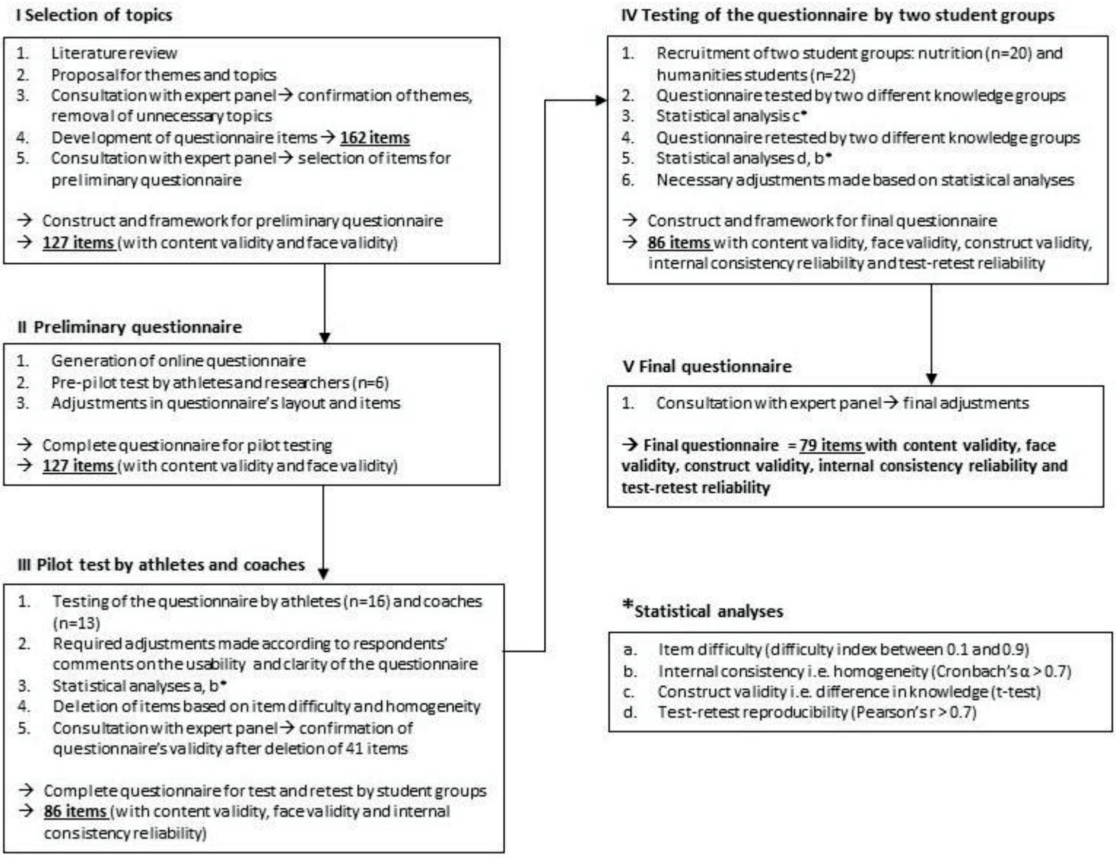


**Figure 6.** Development of nutrition knowledge questionnaire for young endurance athletes and their coaches. Figure inspired by Whati et al.[72] and Feren et al.[74]

## Selection of topics

The topics and the framework for the questionnaire were chosen on the basis of a literature review and consultation of the expert panel. The primary focus of the questionnaire was thus on general nutrition recommendations, athletic performance, recovery, fluids, supplements, and weight control. Together with the expert panel, a true/false format was chosen for the items, a pool of 162 items was generated and the demographic question section was designed. The expert panel confirmed the items' content and face validities. After the expert panel's assessment, 41 items were discarded, 20 items were edited, and 6 new items were added.

## Preliminary questionnaire

The preliminary questionnaire had 127 items with content and face validity. The questionnaire was divided into two sections: demographic background and sports nutrition knowledge, and then further into five subsections: 1) Nutrition recommendations for endurance athletes, 2) Dietary supplements, 3) Fluid balance and hydration, 4) Energy intake and recovery, and 5) Association between food choices and body image. Two young athletes and four researchers pre-pilot tested the questionnaire and the required adjustments were made according to their feedback.

## Pilot test

Sixteen cross-country skiers (17.0±1.8 years) and 13 cross-country skiing coaches (41.3±10.0 years) piloted the preliminary questionnaire. They also gave written feedback on its user-friendliness and clarity. The aim of piloting was to remove the items that would reduce the general appropriateness of the questionnaire for the target group[137] by measuring the item difficulty and internal consistency reliability of the questions. Item difficulty refers to the degree of similarity in the answers to the items.[67] Often the item difficulty index is set between 0.2–0.8[76], meaning that the items answered correctly by 20–80% of the participants are considered discriminating. In this study, the difficulty index was set between 0.1–0.9, because setting the index between 0.2–0.8 resulted in the exclusion of 12 important items. Forty-four items of the questionnaire were answered correctly by over 90% of the respondents. None of the items were so difficult that only under 10% of the respondents answered them correctly. Some of these 44 items were regarded as essential for sports nutrition knowledge. Therefore, the items answered incorrectly by over 10% of the athletes but not by 10% of all participants were kept for further analysis. Ninety-two items remained, for which Cronbach's α was 0.88. The items reducing Cronbach's α were then removed.

Subsequently, the expert panel was consulted about the context of the questionnaire and whether to keep or remove some of the items regardless of their effect on the decreased statistical value in some sections.[137] Following this, 86 items (Cronbach's α 0.87) were left in the questionnaire. Cronbach's α for the five subsections varied from 0.12 to 0.77, but the number of items in these sections was small (5–14 in 4 of 5 sections). Thus, they were combined into broader sections and their Cronbach's α were: 'Nutrition recommendations for endurance athletes and body composition' 0.81 and 'Energy and fluid intake and dietary supplements' 0.72.

### Testing by two student groups

Master's students in nutrition and humanities tested (n = 20 and n = 22) and retested (n = 14 and n = 15) the questionnaire and gave feedback on it. The hypothesis was that the nutrition students would score higher than the humanities students, measured using the independent sample t-test.[67,74] Confirming the hypothesis, the nutrition students obtained significantly higher knowledge scores than the humanities students (78 vs 69, $p < 0.001$). In this study, the time interval between the tests was five weeks. The correlation coefficient was 0.85 for all sections together, 0.87 for 'Nutrition recommendations for endurance athletes and body composition' and 0.63 for 'Energy and fluid intake and dietary supplements'. The correlation coefficients were significant in each section. The test-retest reproducibility for all sections together was thus significant, meaning that the results of the same participants in two separate test sessions were in agreement.[67,76]

### Final questionnaire

The expert panel reviewed the final version of the pilot questionnaire. After their suggestions, seven items were removed and other minor adjustments were made. The final questionnaire had 79 items with high content, as well as face and construct validities, both as internal consistency and test-retest reliabilities. The questionnaire was in three languages: Finnish, Swedish and English (Appendix 1). The English and Swedish versions were directly translated from Finnish but were not back-translated to check wording accuracy. The final questionnaire was used in Studies II (as such) and III (with 78 items – the item 'Consuming fatty food leads easily to weight gain' was removed from the original questionnaire because it proved to be unclear and inappropriate for the target group).

## 4.2.2 Nutrition knowledge of young Finnish endurance athletes and their coaches (Study II)

The previously created and validated questionnaire with 11 demographic questions and 79 statements was used to assess the nutrition knowledge of 94 endurance coaches and 333 endurance athletes. Of these, 21 athletes were rejected as they were not 16–20 years old. The questionnaire was available both online and as a paper copy. Of the coaches, 66 completed the online version and 32 the printed version, and of the athletes 84 and 228, respectively. The athletes and coaches were recruited through open invitation either via e-mail from different high schools, major sports clubs, the elite training groups of the Finnish Ski, Biathlon, Orienteering and Triathlon Associations, the Finnish Athletic Federation. They were also recruited directly at sports high schools or at different training camps for endurance athletes. All the athletes and coaches who were present at the camps or during school days completed the questionnaire. The response rate of the participants who received the online questionnaire could not be calculated. The coaches were asked to send the questionnaire link to their athletes, but were not requested to inform the researchers whether they actually sent it or to how many. Thus, the participant population was regarded as a convenience sample.

### 4.2.3 Nutrition intervention of young Finnish endurance athletes (Study III)

The national- and international-level endurance athletes, aged 16–20, were recruited via endurance coaches from two Finnish sport academies, the Finnish Military Sport Federation and two sports clubs. The intervention participants were randomized into two groups using random permuted blocks, stratified by sex. In this thesis, the EDU group refers to those who attended participatory nutrition education sessions. The EDU+APP group refers to those who attended participatory nutrition education sessions supplemented by the use of the mobile app. The number of participants in the groups was based on power size calculations derived from the results of Study II. In Study II, the mean difference between the knowledge of athletes and coaches was 8 points (SD: 9), measured using a 79-item questionnaire. Therefore, we estimated that the total knowledge score difference that was possible to achieve through the education intervention and which would benefit the participants, would be approximately eight points. Based on the power calculations, we calculated that each group needed 29 athletes ($\alpha = 0.01$, desired power = 0.80). Due to an estimated drop-out rate of 25%, 40 athletes were recruited into both groups. The questionnaire, app and the structure of the education sessions were pilot tested by eleven 16–22-year-old cross-country skiers.

The education intervention consisted of three fortnightly participatory education sessions, which were all attended by both groups. The previously presented questionnaire was used to evaluate the athletes' nutrition knowledge before (wk 0) and after the intervention (wk 5), and after follow-up (wk 17). A food diary was used to assess the athletes' food intake. The diary was completed at baseline and after follow-up. Figure 7 presents the design of the intervention.

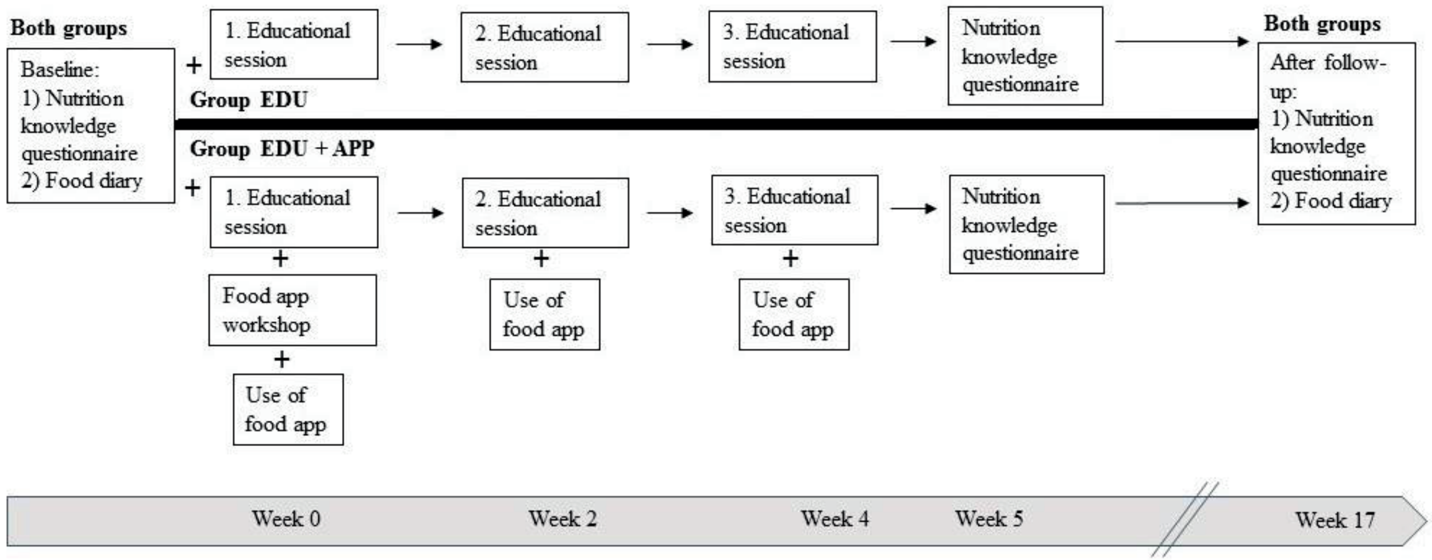


**Figure 7.** Design and schedule of education intervention.

## Dietary assessment

The participants wrote down all the foods and drinks they consumed in a food diary for three successive days (of which one was a weekend day), at baseline, and three months after the last education session. They used The Childrens' Food Picture Book (2015) developed by the University of Helsinki, Seinäjoki University of Applied Sciences and Folkhälsan Research Center for estimating the amounts of the foods. The food diary data were entered and the nutritional composition of diet calculated using AivoDiet dietary software (version 2.2.0.1, Mashie, Sweden) which employs the national food composition database Fineli Release 16 (2013).

The athletes received written feedback on their food diaries at baseline and after follow-up. The feedback focused on the dietary intakes of foods and drinks but not dietary supplements. The feedback highlighted the main strengths and targets for development in their diet, as both gave a rough estimation of daily total energy expenditure (TEE). TEE was calculated using the Harris-Benedict equation for resting energy expenditure (REE) and was multiplied by the estimated average physical activity level, 2.1.[138] In addition, energy intake, and macro- and micronutrient intakes were shown and compared to recommendations (6–10 $g \cdot kg^{-1} \cdot day^{-1}$ or 8–12 $g \cdot kg^{-1} \cdot day^{-1}$ carbohydrates for moderate- to high-intensity endurance training (1–3 $h \cdot day^{-1}$ or >4–5 $h \cdot day^{-1}$), 1.5–2 $g \cdot kg^{-1} \cdot day^{-1}$ proteins for high volume of intense training and ~1–2 $g \cdot kg^{-1} \cdot day^{-1}$ fat.[22,139]

## Education sessions

The aim of the participatory education sessions was to increase nutrition knowledge by improving the athletes' motivation and learning. Allowing the athletes to participate in the sessions in the form of discussions, tasks and goal setting was supposed to expand their feelings of autonomy, competence and relatedness.[108] The main aim behind the education sessions was to strengthen all these feelings, so the sessions were not divided into parts addressing only relatedness, only competence or only autonomy, as they are so closely interwoven. The progressive education plan was based on the concept of the meaningful learning process (Figure 3), which explains the conversion of real-life challenges (e.g. athletes' inadequate energy intake) into interesting and motivating educational challenges. The education sessions were held by a nutritionist and consisted of lectures, discussions, exercises and individual and group work. Each education session lasted 90 minutes. Their themes were based on the findings of Study II and the literature[4]. The themes and the structure of the education sessions are presented below.

**Session 1**: Importance of nutrition for athletic performance; energy requirements in sports; fluids. **Session 2**: Carbohydrates, fat and protein (sources, quality, timing, current trends) from the viewpoint of endurance athletes.
**Session 3**: Vitamins and minerals (highlighting iron, magnesium, and vitamin D); Supplements; Challenges (eating on competition days, eating on the road, DE and weight control).

**Session 1**:

| | Subject | Type of work |
|---|---|---|
| 1 | Introduction to topic: important role of nutrition in endurance sports<br>Questions and discussion: Why is nutrition important to you? Why are you here today? | Lecture<br>Discussion |
| 2 | Energy requirements: in different sports, in endurance sports, during different seasons; good sources of energy, amounts, concrete examples | Lecture |
| 3 | Task 1: How much energy nutrients do you need? Calculate and write them down. (carbohydrates 6–10 $g \cdot kg^{-1} \cdot day^{-1}$, protein 1.5–2 $g \cdot kg^{-1} \cdot day^{-1}$ and fat 1–2 $g \cdot kg^{-1} \cdot day^{-1}$) | Individual work |
| 4 | Task 2: Where can you get such amounts of energy nutrients in one day? Think of your normal training day this season. Write down concrete examples. Use the tables provided or Fineli food database. The topic will be discussed later. | Individual work<br>Discussion |
| 5 | Fluids: importance, amounts needed, different types of fluids | Lecture |
| 6 | Homework: take a look at food packages at home and at a supermarket. Concentrate on the amount of macronutrients in them. Which are good sources of carbohydrates, protein or fat? | |

**Session 2**:

| | Subject | Type of work |
|---|---|---|
| 1 | Opening: highlights from group discussions of previous session, introduction to today's topic, going through the homework and continuing Task 2 from last session | Lecture |
| 2 | Carbohydrates: importance; sources; quality and amounts; timing; usage before, during and after training; carbohydrate loading | Lecture |
| 3 | Task 1: Take a look at the carbohydrate sources you wrote down last time. What kind of sources did you choose? Would you make the same choices again? | Individual work<br>Discussion |
| 4 | Task 2: Write down healthy and good carbohydrate sources for the following meals: lunch during a school day, snack prior to training (training two hours later), breakfast prior to competition | Individual/group work<br>Discussion |
| 5 | Fat: importance; sources; quality and amounts; timing; trends (e.g. butter and coconut) | Lecture |
| 6 | Task 3: How can you increase the amount of unsaturated fat in your diet? What would be concrete food choices or actions? | Group work/discussion |
| 7 | Protein: importance; sources; quality and amounts; timing; trends | Lecture |
| 8 | Homework: Add good sources of unsaturated fats to your diet, and try products that are new to you | |

**Session 3**:

| | Subject | Type of work |
|---|---|---|
| 1 | Opening: highlights from group discussions of previous session, introduction to today's topic, going through homework | Lecture |
| 2 | Vitamins and minerals: recommendations and sources (highlighting iron, magnesium and vitamin D) | Lecture |
| 3 | Task 1: Take a look at your notes from Task 1 in the first session. Did you choose good sources of iron, and vitamin D? Would you make the same choices again? | Individual/group work<br>Discussion |
| 4 | Supplements: general information, recommendations, examples of supplements that could be used by young endurance athletes | Lecture |
| 5 | Eating on competition days and on the road: examples from athletes | Discussion |
| 6 | Weight control and disordered eating among athletes: facts, tips, risks | Lecture<br>Discussion |

## Mobile app intervention

The athletes in the EDU+APP group used the food application, MealLogger®, for four days after each education session. The app had two main functions. First, during the photographing periods after the sessions, the athletes were asked to log everything they ate or drank. They were given specific tasks to concentrate on when taking pictures and/or writing descriptions, which are presented below. These tasks were also used to strengthen athletes' feelings of autonomy and competence. Second, the nutritionist sent them feedback via the app to support their learning and to reinforce their feelings of relatedness. The athletes were instructed on how to use the food application after the first education session.

**Week 1. Eating rhythm and fluids:** The athletes were asked to concentrate on the number and timing of meals, and the amount of fluids in their diet. They were given feedback on these points twice.

**Week 2. Healthy eating:** Feedback was given daily on the quality of breakfast, lunch and dinner. Before receiving the feedback, the athletes were asked for a self-evaluation of their meals. Both self-evaluation and feedback were given in the form of 0 to 5 stars. A star was given when the meal contained one of the following: a source of carbohydrate, fibre, protein, unsaturated fat, and something colourful (vegetables, fruits, berries).

**Week 3. Variety of food + vitamin D:** The athletes were asked to concentrate on the sources of vitamin D in their diets and to log alongside their photographs the foods containing vitamin D. They were also encouraged to try new foods and eat a wide variety of foods. They received feedback on the sources of vitamin D and the versatility of their meals in the middle and at the end of the week.

## 4.3 Statistical methods

All statistical analyses were conducted using IBM SPSS Statistics for Windows (version 24.0; IBM Corp., Armonk, NY). P-values below 0.05 were considered statistically significant.

Study I began with a pilot study which aimed to remove the items that reduced the appropriateness of the questionnaire for the target population. This was done by applying the item analysis feature of the SPSS statistical package. In this study, the items answered incorrectly by over 10% of the athletes but not by 10% of all respondents were kept for further analysis and considered discriminating items. The internal consistency reliability of the whole questionnaire and all knowledge sections separately was measured using Cronbach's α test aiming for at least 0.7. The difference in between the knowledge in the two groups was measured using the independent sample t-test. Test-retest reproducibility was evaluated using Pearson's correlation.

In Study I, as in this thesis overall, 'nutrition knowledge score' referred to the proportion (%) of correct answers, presented as mean ± standard deviation (SD) or mean ± 95% confidence intervals (CI). The maximum points were 79 (Study I and II) and 78 (Study III). Each correct answer yielded one point, and each wrong answer zero points. The online questionnaires did not allow any questions to be left blank, but the printed versions of the questionnaires had some missing values. Although the amount of missing values was negligible, the mean knowledge score of a participant was always calculated without the missing scores.

Study II used an independent sample t-test to compare the differences between two groups, and one-way analysis of variance (ANOVA) to compare the differences between multiple groups. Post-hoc tests (Tukey) were used for determining which groups differed significantly from each other.

In Study III, the normality of the variable distributions was identified using the Kolmogorov-Smirnov test. We used repeated measures ANOVA adjusted for age, sex and main sport for comparing the groups in terms of knowledge score, dietary intake variables and their changes over time. For macronutrient intakes, direct data derived from dietary software were used instead of Willett's[140] energy-adjusted intakes, as the differences in the values were only minor. Potential under-reporters were not excluded, because the differences in the analyses were minor. The categorical data were presented as numbers and percentages (Study II and III).

Mean and 95% confidence intervals were presented for knowledge and dietary intake variables.

# 5 Results

## 5.1 Characteristics of the participants

Table 7 presents the descriptive data on the participants in Study II and III. In Study II, the two main sports were cross-country skiing (n = 53 coaches and n = 111 athletes) and orienteering (n = 13 and n = 110). In Study III, the two main sports were cross-country skiing (n = 33) and endurance running/race-walking (n = 18). A quarter of the athletes of both studies were members of national teams.

**Table 7.** Background information of athletes participating in Studies II and III.

| | STUDY II Number of athletes | Percentage of athletes | STUDY III Number of athletes | Percentage of athletes |
|---|---|---|---|---|
| **Main sport[a]** | | | | |
| Cross-country skiing | 111 | 35.7 | 33 | 41.8 |
| Biathlon | 38 | 12.2 | 13 | 16.5 |
| Orienteering[b] | 110 | 35.3 | 13 | 16.5 |
| Cycling | 1 | 0.3 | 0 | 0 |
| Triathlon | 13 | 4.2 | 2 | 2.5 |
| Swimming, rowing, canoeing | 7 | 2.3 | 0 | 0 |
| Endurance running and race-walking | 25 | 8.0 | 18 | 22.8 |
| Athletics[c] | 6 | 1.9 | 0 | 0 |
| **Best placing in Finnish championships[d]** | | | | |
| Top 3 in current season | 80 | 26.7 | 29 | 36.7 |
| Top 3 in former season | 60 | 20.0 | 9 | 11.4 |
| Top 3 earlier | 24 | 8.0 | 5 | 6.3 |
| 4–10 in current season | 45 | 15.0 | 17 | 21.5 |
| 4–10 earlier or year not defined | 43 | 14.3 | 8 | 10.1 |
| 11+ | 48 | 16.0 | 11 | 13.9 |
| **Part of any team coaching group** | | | | |
| No | 52 | 16.7 | 0 | 0 |
| Yes | 260 | 83.3 | 79 | 100 |
| In national team | 78 | 25.0 | 20 | 25.3 |
| In national B team or in military sport federation | 9 | 2.9 | 10 | 12.7 |
| In another official training group of Finnish sport federations for talented athletes | 56 | 17.9 | 10 | 12.7 |

[a]1 missing value in Study II, [b]Including orienteering, mountain bike- and ski orienteering, [c]Other sports, [d]12 missing values in Study II

Of the 94 coaches in Study II, 36% were experts and 33% senior experts by profession. Of all the coaches, 45% had a university degree, and more specifically, ten (11%) had a university degree in sports and exercise science. Eight (8.5%)

coaches were students and three (3.2%) were retired. Over half of the coaches (55%) coached both individual athletes and groups, and a quarter of them only individual athletes. Their coaching experience varied from 0–2 years (8.5%) to over 20 years (16%), the median coaching experience being 6–10 years.

The athletes of Study III were divided into two groups (group EDU = participatory nutrition education sessions alone and group EDU+APP = participatory nutrition education sessions and the mobile app) and their background information is presented in Table 8. Apart from one participant, all the athletes attended the first education session. Seventy athletes were present at the second session and 59 at the third. All the participants completed the first questionnaire, 66 the second and 67 the third. In week 0, 73 participants completed the food diary and at the end 67. Of the 42 participants in the EDU+APP group, 34 (81%) actually used the app.

**Table 8.** Background information on athletes of Study III presented as numbers and percentages of participants in group. The EDU group refers to participatory nutrition education sessions. The EDU+APP group refers to participatory nutrition education sessions and the mobile app.

| | Group EDU (n = 37) | Group EDU+APP (n = 42) |
|---|---|---|
| **Sex** | | |
| female | 18 (49%) | 17 (40%) |
| male | 19 (51%) | 25 (60%) |
| **Main sport** | | |
| Cross-country skiing | 15 (41%) | 18 (43%) |
| Biathlon | 5 (14%) | 8 (19%) |
| Orienteering | 8 (22%) | 5 (12%) |
| Endurance running and race-walking | 9 (24%) | 9 (21%) |
| Triathlon | 0 (0%) | 2 (5%) |
| **Completion of questionnaire** | | |
| 1st (Week 0) | 37 (100%) | 42 (100%) |
| 2nd (Week 5) | 31 (84%) | 35 (83%) |
| 3rd (Week 17) | 29 (78%) | 38 (90%) |
| **Completion of food diary** | | |
| 1st (Week 0) | 33 (89%) | 40 (95%) |
| 2nd (Week 17) | 30 (81%) | 37 (88%) |

## 5.2 Nutrition knowledge of Finnish endurance athletes and coaches

Table 9 presents the nutrition knowledge scores of the athletes and coaches in Study II. The baseline results of the athletes' nutrition knowledge scores from Study III are combined in the same table. Both the total knowledge scores and the scores for each section of the questionnaire are presented. The coaches obtained higher total knowledge scores and scores for each section than the athletes in Studies II and III. The knowledge scores of the athletes in Study III were higher than those of the athletes in Study II. The coaches in Study II answered 81% of the questions correctly, on average and the athletes 73%. In Study III, the athletes answered 78% of the questions correctly, on average. There was no statistically significant difference between the knowledge scores of the athlete groups in Study III. However, in Study II, the difference between the knowledge scores of the athletes and coaches was statistically significant. The 'Dietary supplements"' section was the most difficult section for the athletes in Study II and at baseline in Study III. For the coaches, the 'Nutrition recommendations for endurance athletes' section proved to be the most difficult.

In Study II, the lowest total knowledge score among athletes was 47% and among coaches 58%. The highest total knowledge scores were 92% and 95%, respectively. Of the athletes, 51% had a knowledge score lower than the mean score; of the coaches 44%. In Study III, at baseline, the lowest total knowledge score among the athletes was 60% and the highest 94%. Of the athletes, 48% had a knowledge score lower than the mean score. In Weeks 5 and 17, the lowest and highest total knowledge scores were 68% and 96% (wk 5) and 65% and 99% (wk 17), respectively.

The female athletes in Study II obtained higher total knowledge scores than the male athletes (74.1% vs 71.4%; $p = 0.005$). The female coaches also obtained higher total knowledge scores than the male coaches (84.6% vs 79.4%; $p=0.004$). In Study III, the situation was the opposite. The male athletes obtained numerically higher total knowledge scores (wk 0: 78.3%, wk 5: 87.7, wk 17: 86.4) compared to female athletes (wk 0: 77.6%, wk 5: 85.0, wk 17: 83.4). However, the difference was not statistically significant ($p = 0.190$).

The results from Study II showed a positive association between the age and nutrition knowledge of the athletes ($p = 0.001$). Among the coaches, nutrition knowledge was negatively associated with age ($p < 0.001$). The coaches and athletes of Study II gave an estimation of their own nutrition knowledge in advance. The coaches who regarded their nutrition knowledge as excellent obtained higher knowledge scores than the coaches who regarded their knowledge as only satisfactory (84.4% vs. 71.2%; $p=0.001$). Among the athletes, the difference was not statistically significant even though a similar tendency was seen. In Study II, the athletes who were in a national team obtained numerically higher total knowledge scores (75.0%) than the athletes who were not (72.0%). However, the difference was not significant ($p = 0.10$).

**Table 9.** Mean nutrition knowledge scores as percentages of correct answers (95% confidence intervals in parenthesis) for the whole questionnaire and in different sections (n = 5) of the questionnaire. The results from Study II are presented, as are the baseline results from Study III. The results of Studies II and III are combined in the same table and not compared statistically to each other.

| | Study II<br>Athletes | Study II<br>Coaches | Study III<br>Athletes in EDU group (n = 28) at baseline | Study III<br>Athletes in EDU+APP group (n = 34) at baseline |
|---|---|---|---|---|
| **Nutrition recommendations for endurance athletes** | 69.2<br>(68.1 to 70.4) | 76.8*<br>(74.6 to 79.0) | 75.8<br>(72.7 to 79.0) | 75.2<br>(71.8 to 78.6) |
| **Dietary supplements** | 66.0<br>(63.5 to 68.5) | 79.8*<br>(75.7 to 83.8) | 71.4<br>(62.3 to 80.5) | 73.5<br>(67.6 to 79.4) |
| **Fluid balance and hydration** | 85.2<br>(83.5 to 86.9) | 90.9*<br>(88.7 to 93.1) | 87.2<br>(82.6 to 91.9) | 87.8<br>(84.2 to 91.4) |
| **Energy intake and recovery** | 72.8<br>(71.4 to 74.3) | 82.0*<br>(79.7 to 84.4) | 77.3<br>(72.6 to 82.0) | 77.9<br>(73.3 to 82.6) |
| **Association between food choices and body image** | 84.0<br>(82.3 to 85.6) | 91.4*<br>(89.4 to 93.4) | 83.3<br>(77.8 to 88.9) | 87.9<br>(84.1 to 91.7) |
| **Total** | 72.7<br>(71.8 to 73.7) | 80.8*<br>(79.1 to 82.6) | 77.7<br>(74.9 to 80.5) | 78.2<br>(75.5 to 80.9) |

*statistically significant ($p<0.005$) difference between coaches' and athletes' nutrition knowledge scores

### 5.2.1 Effects of nutrition education intervention on nutrition knowledge

The mean nutrition knowledge scores of both intervention groups increased significantly during Study III ($p < 0.001$). Figure 8 presents the changes in nutrition knowledge. The knowledge scores of the EDU and EDU+APP groups did not differ ($p = 0.309$). The mean scores throughout the study for all participants together were 78% (wk 0), 86% (wk 5) and 85% (wk 17). At their lowest, the mean nutrition knowledge scores were 77.7% (SD: 7.6) (EDU group, wk 0) and at their highest 87.4% (SD: 7.6) (EDU+APP group, wk 5). A comparison of the scores in Week 17 to those in Week 0 showed that the mean change in knowledge was 6.1 (SD: 3.7) points in the EDU group and 7.3 (SD: 6.0) in the EDU+APP group. Directly after the education sessions, the mean change in knowledge among the athletes was 6.9 (SD: 6.2) points in the EDU group and 9.3 (SD: 6.7) in the EDU+APP group.

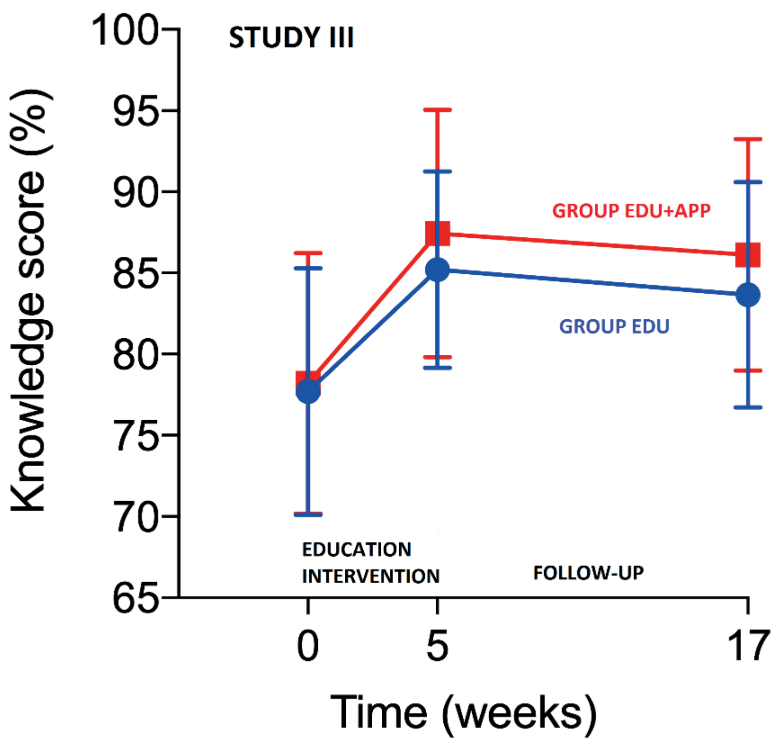


**Figure 8.** Mean total nutrition knowledge scores (± SD) at baseline, after nutrition education and after follow-up. Red represents the EDU+APP group (education sessions + use of mobile food app) and blue line the EDU group (education sessions only). $P = 0.309$ for group*time interaction, $p < 0.001$ for main effect of time, and $p = 0.309$ for main effect of group.

The trend of the changes in nutrition knowledge was similar in all sections of the questionnaire (Table 10). The athletes in the EDU+APP group obtained slightly higher knowledge scores than the athletes in the EDU group, but the differences were not significant ($p = 0.217$ to 0.771). There was a significant increase in the mean scores at the different measurement times in Sections 1–4 ($p < 0.001$) of the questionnaire but not in Section 5 ($p = 0.142$). The scores were the best in the 'Fluid balance and hydration' section throughout the study. In Week 0, 'Dietary supplements' was the most difficult section.

The athletes who used the mobile app obtained significantly better nutrition knowledge scores than those who did not actually use the app even though they belonged to the EDU+APP group (score 1: 80 vs 68; score 3: 87 vs 76) ($p < 0.001$).

**Table 10.** Mean nutrition knowledge scores of athletes (95% confidence intervals in parenthesis) in different sections (n = 5) of questionnaire in Study III. EDU group refers to participatory nutrition education sessions. EDU+APP group refers to participatory nutrition education sessions and use of mobile app.

| Section | Week 0 EDU (n = 28) | Week 0 EDU+APP (n = 34) | Week 5 EDU (n = 28) | Week 5 EDU+APP (n = 34) | Week 17 EDU (n = 28) | Week 17 EDU+APP (n = 34) | p-value (group* time inter-action) | p-value (main effect of time) |
|---|---|---|---|---|---|---|---|---|
| **1: Nutrition recommendations for endurance athletes** | 75.8 | 75.2 | 82.8 | 83.6 | 80.9 | 83.7 | 0.103 | <0.001 |
| | (72.7 to 79.0) | (71.8 to 78.6) | (79.8 to 85.8) | (79.5 to 87.7) | (77.7 to 83.9) | (80.9 to 86.4) | | |
| **2: Dietary supplements** | 71.4 | 73.5 | 88.6 | 90.6 | 82.1 | 90.0 | 0.276 | <0.001 |
| | (62.3 to 80.5) | (67.6 to 79.4) | (81.5 to 95.7) | (86.5 to 94.7) | (75.1 to 89.2) | (85.2 to 94.8) | | |
| **3: Fluid balance and hydration** | 87.2 | 87.8 | 91.8 | 94.5 | 93.4 | 94.1 | 0.689 | <0.001 |
| | (82.6 to 91.9) | (84.2 to 91.4) | (89.2 to 94.5) | (91.4 to 97.7) | (90.0 to 96.7) | (90.5 to 97.7) | | |
| **4: Energy intake and recovery** | 77.3 | 77.9 | 86.2 | 88.2 | 85.7 | 85.3 | 0.648 | <0.001 |
| | (72.6 to 82.0) | (73.3 to 82.6) | (82.4 to 90.0) | (84.2 to 92.2) | (81.8 to 89.6) | (81.4 to 89.2) | | |
| **5: Association between food choices and body image** | 83.3 | 87.9 | 88.1 | 88.6 | 86.9 | 90.8 | 0.345 | 0.142 |
| | (77.8 to 88.9) | (84.1 to 91.7) | (83.6 to 92.6) | (84.6 to 92.5) | (83.2 to 90.6) | (87.5 to 94.2) | | |

P > 0.05 for main effect of group

The athletes in Study III were asked to give voluntary feedback on the intervention after the last education session. Thirteen gave written feedback and many athletes gave verbal feedback either individually, directly to the nutritionist or in the classrooms during the sessions. In general, the feedback on the different parts of the intervention was highly positive.

## 5.3 Energy and macronutrient intakes

Table 11 presents the athletes' energy and macronutrient intakes at baseline and after follow-up in Study III. Some positive changes were seen in the dietary intakes of the athletes, but the differences were not significant ($p > 0.05$). Even though the athletes' energy intake increased, it remained under the estimated energy expenditure both at baseline and after follow-up. Carbohydrate intake also increased slightly but still remained below the recommendations (6–10 $g \cdot kg^{-1} \cdot day^{-1}$) throughout the study.

The mean weight of the athletes in the EDU group was 64 kg in Week 0 and 65 kg after follow-up. In the EDU+APP group, it was 66 kg and 68 kg, respectively. The increase in weight during the study was significant (main effect of time: $p = 0.001$). The weight also affected the rough estimated energy expenditures of the athletes which were, on average, between 3400 and 3600 $kcal \cdot day^{-1}$.

The male athletes' average energy, carbohydrate, protein and fat intakes were significantly ($p < 0.05$) higher than the female athletes' corresponding intakes. The athletes' fibre intake increased significantly ($p = 0.001$) during the intervention. At baseline, fibre intake was 32.5 $g \cdot day^{-1}$ in the EDU group and 32.1 $g \cdot day^{-1}$ in the EDU+APP group. After the intervention, it was 35.1 and 38.1 $g \cdot day^{-1}$, respectively. There was no significant ($p = 0.181$) change between the groups' fibre intake. In terms of intakes of sugar and fatty acids (both saturated, monounsaturated and polyunsaturated fatty acids), group*time interaction, time or group had no statistically significant main effects.

**Table 11.** Mean energy and macronutrient intakes (95% confidence interval in parenthesis) of athletes in Study III. EDU group refers to participatory nutrition education sessions. EDU+APP group refers to participatory nutrition education sessions and use of mobile app.

| | **Week 0 EDU (n = 30)** | **Week 0 EDU+APP (n = 37)** | **Week 17 EDU (n = 30)** | **Week 17 EDU+APP (n = 37)** |
|---|---|---|---|---|
| **Energy intake** | | | | |
| $kcal \cdot day^{-1}$ | 2739 (2404 to 3074) | 2931 (2677 to 3184) | 2750 (2434 to 3067) | 3124 (2842 to 3407) |
| **Carbohydrate** | | | | |
| $g \cdot day^{-1}$ | 320 (278 to 362) | 344 (311 to 378) | 327 (287 to 366) | 368 (327 to 409) |
| $g \cdot kg^{-1} \cdot day^{-1}$ | 4.9 (4.4 to 5.5) | 5.2 (4.7 to 5.7) | 5.0 (4.5 to 5.6) | 5.4 (4.9 to 6.0) |
| % of total energy | 47 (44 to 49) | 47 (45 to 49) | 48 (46 to 50) | 47 (45 to 48) |
| **Fat** | | | | |
| $g \cdot day^{-1}$ | 98 (83 to 114) | 102 (93 to 112) | 94 (81 to 107) | 108 (98 to 118) |
| $g \cdot kg^{-1} \cdot day^{-1}$ | 1.5 (1.3 to 1.7) | 1.5 (1.4 to 1.7) | 1.4 (1.3 to 1.6) | 1.6 (1.5 to 1.7) |
| % of total energy | 32 (30 to 34) | 31 (30 to 33) | 31 (29 to 32) | 31 (30 to 33) |
| **Protein** | | | | |
| $g \cdot day^{-1}$ | 121 (106 to 135) | 135 (121 to 150) | 124 (109 to 139) | 143 (130 to 156) |
| $g \cdot kg^{-1} \cdot day^{-1}$ | 1.9 (1.7 to 2.0) | 2.0 (1.8 to 2.3)[a] | 1.9 (1.7 to 2.1) | 2.1 (1.9 to 2.3)[a] |
| % of total energy | 18 (17 to 19) | 18 (17 to 19) | 18 (17 to 19) | 19 (18 to 20) |

[a] $p = 0.044$ for main effect of actually using app

# 6 Discussion

## 6.1 Main findings

Nutrition knowledge can be reliably evaluated using adequately validated questionnaires. As a suitable, validated questionnaire for evaluating the nutrition knowledge of young Finnish endurance athletes and their coaches did not previously exist, we created and validated such a questionnaire – a nutrition knowledge questionnaire – which we used to measure the nutrition knowledge of the athletes and coaches. The results of this thesis study show that there are gaps in young Finnish endurance athletes' and their coaches' nutrition knowledge. The athletes' nutrition knowledge was limited, especially that related to dietary supplements. The coaches' main gaps in nutrition knowledge were related to the general nutrition recommendations for endurance athletes. The athletes' nutrition knowledge significantly increased in both intervention groups during a structured, motivational and science-based nutrition education intervention, consisting of three education sessions and the completion of two food diaries. The use of a mobile food app by one intervention group as an education method was not, however, successful in further improving their knowledge.

The nutrition education intervention had some effects on the athletes' dietary habits and subsequent dietary intakes, but the changes in the dietary intakes were only small. Already at the beginning of the intervention, the dietary intake of the athletes was rather good in comparison to the present Finnish nutrition recommendations and nutrient intake among the general adult population. However, the athletes' energy intakes were below their estimated energy needs at both baseline and the end of the intervention. Moreover, their carbohydrate intakes remained below the recommendations for endurance athletes throughout the intervention.

## 6.2 Strengths and weaknesses of design and methods

### 6.2.1 Participants

The gender and age distributions of the athletes were relatively even in all the studies. Less than a third of the coaches in Study II were women. However, this fairly accurately reflects the ratio between men and women among Finnish endurance sport coaches: a report from 2016 concluded that 78% of professional coaches in Finland were men.[141] As the confounding factors of the studies were minimized at baseline, the differences between the groups in the study outcomes were mainly due to the differences in the education intervention, and not to differences between the athletes' baseline characteristics.

The participants in Study II were from multiple regions of Finland and in Study III from five different regions in south, west-coast and north Finland. Thus, regionally, they represent a large part of Finland and can be regarded as a relatively representative population of Finnish endurance athletes, especially in Study II. The age range of the athletes was 16–20 years. We regarded this as a critical age for nutrition education, because at this age many of the Finnish, goal-oriented endurance athletes start sports high-school or university studies. It is typical that these athletes have to move from their parental home in search of better training opportunities. As a result, they no longer have parents providing food or cooking for them on a daily basis. This applied especially in Study III, in which all the athletes from the Finnish Military Sport Federation, the majority of the athletes of the sports academies, and some of the athletes of the sports clubs had already moved from their parental home. This was confirmed by consulting their coaches. At this age, training volumes and intensities also increase and are of a considerably higher level than those of child athletes. Due to this, and to support young athletes' normal growth and development, the maintenance of adequate energy and nutrient intake is of utmost importance.

A selection bias was admittedly introduced, as the vast majority of athletes were high-school students or graduates, and recruitment was carried out in high schools but not in other schools. On the other hand, in Finland most sports schools for endurance athletes are high schools and it is likely that the majority of Finnish endurance athletes choose these instead of vocational schools or other options.

The recruitment of participants was rather challenging. In all the studies, the main way of contacting the participants was via email. However, this was not the optimal method for contacting young athletes. The most effective way of contacting them proved to be during training camps or by visiting sports high schools. Some of the emails were sent directly to the potential participants, but most went through coaches who voluntarily forwarded the message to their athletes. This kind of recruitment procedure led to one of the limitations of this thesis study. It was not possible to calculate the response rate of the participants because the number of athletes and coaches that the emails and other invitations had reached could not be determined. Therefore, the population of participants was regarded as a targeted sample. Although calculating the response rate would have yielded interesting information on athletes and coaches, a targeted sample was the best available method to contact and recruit the number of participants in the current setting. It should also be noted that almost all the athletes attending the high schools and camps chosen for this study were reached.

Another limitation was that the number of athletes in the intervention may have been too small for us to detect considerable changes in diet. The power calculations were made assuming that the nutrition knowledge score would increase by eight points. That number was obtained when the scores of the athletes and coaches in Study II were compared with each other. The desired power was probably sufficient for the knowledge analyses, but it might have been insufficient for the food analyses. Overall, this is not a great problem, since knowledge score was the primary outcome of the studies and dietary intake was only secondary.

Approximately one fifth of the athletes withdrew from the study. No factors regarding age, gender, nutrition knowledge level or choice of sports explained the drop outs and thus, the reasons were interpreted as being unsuitable schedules or lack of time or motivation. The proportion of athletes who did not use the app in the EDU+APP group was also moderate (19%). This may be explained by the fact that many of them liked to use the app and did not see it as too laborious or difficult. Interestingly, the athletes in the EDU+APP group who did not use the app obtained significantly poorer knowledge scores than those who used the app. For these athletes, the use of the app may have been too laborious, which may also reflect their overall motivation for nutrition education.

A strength in Studies I and II was that the nutrition knowledge of the coaches, not only the athletes, was measured, and that the coaches were also consulted when designing and piloting the questionnaire. The questionnaire had good validity and reliability, and the items were based on the latest scientific information. Coaches are among the most important sources of nutrition information for their athletes[77] and therefore it was important to extend the study to them for all future implications of the results.

### 6.2.2 Design of sub-studies

The creation and validation of the nutrition knowledge questionnaire in Study I followed the steps of previously published studies.[72,74] Even though the questionnaires created in these studies were used among urban South-African adolescents[72] and obese Norwegian adults[74], their steps seemed suitable for questionnaires for young Finnish athletes', especially since they had been utilized in developing questionnaires for diverse study populations. Our interest was in adolescents and a Nordic population. The use of an external expert panel specialized in sports nutrition was essential for generating the items and for the items' content and construct validities[67], as the design of the questionnaire development was not specifically for sports nutrition.

A limitation of the questionnaire validation process was that it measured internal consistency using Cronbach's α test instead of, for example, the Kuder-Richardson formula 20 (KR-20). Cronbach's α test is primarily designed for continuous variables, whereas KR-20 is for dichotomous items.[67,142] In our studies, all the items were dichotomous. However, even though it is not primarily meant for such data, Cronbach's α can also be used with dichotomous data. When it is, it produces scores identical to KR-20. It should also be noted that the number of items in a questionnaire may affect its value. The reliability of a questionnaire consisting of several sections increases both when the correlations between the items in the different sections increase and when the total number of somewhat similar items increase.[143]

The design of Study II was cross-sectional. As we wanted to gain more insight into the nutrition knowledge of young endurance athletes and their coaches, the design suited our objectives. The results of Study II revealed the knowledge level at a specific time point, but did not allow for the determination of causality. However, the latter was beyond the interest of the current thesis.

Study III was a randomized intervention. The athletes were randomized into two groups, stratified by sex. In the EDU group, the athletes participated in nutrition education sessions. The EDU+APP group attended these participatory nutrition education sessions and used a mobile food app after the sessions. Both groups completed the same questionnaires and food diaries and received feedback on the diaries. The contents of the education sessions were based on a literature review on young athletes' main nutritional demands and on information regarding athletes' nutrition knowledge from the results of Study II. This approach was used to better fill any possible gaps in the athletes' knowledge. Based on the main topics selected, it was estimated that three 90-minute education sessions were enough to cover them all. A major strength in Study III was the design of the education sessions. Meaningful learning process and SDT[107,112] were first applied, and the intervention was then piloted with the expert panel and athletes. The thesis study group also included an expert in educational sciences. Another main strength of Study III was that the majority of the athletes attended the education sessions; 99% and 88% were present in the first and second sessions, respectively. Moreover, the completion of the questionnaires and food diaries was of a high level throughout the study, as even at the lowest rate, 84% of the participants completed them. This reflects their motivation and commitment to the study. Many of the participants also gave positive feedback on the education sessions, the personal feedback they received on the food diaries, and the usability of the mobile app.

Having no control group with no nutrition education in the intervention made it difficult to differentiate how much the knowledge changed due to actual learning during the intervention and how much was due to the repetition of the test, in other words, to filling the same questionnaire multiple times. However, the test-retest reproducibility was regarded as significant when the questionnaire was created, and therefore, we can assume that the repetition of the test had no significant effect on the athletes' nutrition knowledge scores. In fact, a control group was not regarded as essential for this study because its main emphasis was on determining whether the use of the mobile app would enhance the influence of the education sessions. We also reasoned that if there had been a group with no education, their drop-out rate would have been higher and the whole recruitment process much harder.

The app was used for four days during each of the three weeks. In the pilot study, the athletes were asked to use the app for a week at a time, but this time period was shortened on the basis of their feedback. In a study by Simpson et al.[123] which aimed to answer relatively similar research questions, the logging period was three days for six weeks. Four days per week for three weeks seemed like a period that the participants would be likely to adhere to. A considerable limitation in the intervention was that peer support, one of the main advantages of the mobile app used for this study and of other similar apps[132], was not utilized. The athletes used the app individually, without seeing the food images of other users. When planning the intervention, it was assumed that individual endurance athletes would not like to share their meal pictures with people whom they possibly did not know, because peer support is not necessarily as common to them as to, for example, team sport athletes. This was confirmed by the athletes participating in the pilot study. When the pilot study participants were asked how they would feel about sharing the images with their peers, the majority did not like the idea. Thus, we chose the individual-use design. Our intervention did indeed succeed in keeping almost all the athletes in the EDU+APP group involved in taking meal pictures. It would be of interest to also know whether the social sharing aspect would have resulted in more effective dissemination of nutrition information[132]. However, this aspect was left for future studies.

### 6.2.3 Nutrition knowledge and dietary intake assessment methods

This study used a questionnaire specially created and validated for the study purpose and target group, because no suitable questionnaires existed. Using a questionnaire that is validated for the target population is a prerequisite for reliable nutrition knowledge assessments[67], and we consider this one of the main strengths of this thesis study. Inadequately validated or even non-validated questionnaires and other tools, such as apps, have been used in many previous studies that have evaluated nutrition knowledge.[70] This limits the wider use of the questionnaires and the validity and utilization of the results of these studies.

The questionnaire for this thesis study was created following a rigorous design process and it underwent several validity and reliability tests. An expert panel was consulted during each step of the validation process to ensure the content and construct of the items[67]. The pilot group that tested the questionnaire was similar to the target group of Studies II and III, thus improving its usability. The questionnaire was made available in both Finnish and Swedish, the two official languages of Finland, enabling all the athletes to complete the questionnaire in their native language. Another factor that improved the user-friendliness of the questionnaire was that its number of items (79) was reasonable: enough to cover the important topics of sports nutrition but not too heavy for the respondents. The number of items was in line with other nutrition knowledge questionnaires, which have had between 20 and 100 questions.[70–74]

One main limitation of the questionnaire, thus concerning all three studies, was that the respondents were unable to choose a 'not sure' option for the items; they could answer only 'true' or 'false'. Some of the respondents may, hence, have guessed part of the answers, thus introducing bias to their measured knowledge estimate. In the pilot study, a few athletes commented that some items were impossible to answer as simply true or false. These items were re-evaluated by the expert panel, who concluded that nutrition misbeliefs and the influence of common but scientifically inadequate beliefs were the main reasons for such comments. All the items chosen for the questionnaire were based on undisputable scientific data and were thus not removed, despite the comments.

In Study III, participants completed a three-day food diary twice. Such a method is burdensome for both participants and researchers, but it can provide detailed information on the food consumption and dietary intake of the participants. In comparison to other typically used methods for measuring food consumption, such as FFQs or 24-h food recalls, a three-day food record was expected to reveal changes in food consumption more precisely. FFQs report the usual intake of various foods over a longer period of time[140] and due to this, it was estimated that possible changes in dietary habits during a relatively short intervention would not be visible. After all, FFQs mainly measure the relative rather than actual intake of energy and other food components.[140] In addition, FFQ data are often more biased than data from multiple-day food records.[144] 24-h food recall which measures actual food intake, on the other hand, was regarded as too short a period of time for detecting changes on the individual level, because the variation in young athletes' diets on a daily level may be quite great and depend on, for example, the number of training sessions and whether or not these are at school. In addition, some foods, such as fish, are not typically eaten daily and this may result in large individual day-to-day variations in nutrient intakes. A three-day food diary can also be seen as an education method that actually forces the athlete to concentrate on food consumption. It requires more input from the participants than a FFQ, for example. Feedback on food records can also be given on a much more precise level than in FFQ reports, which further increases their suitability as an educational tool. However, it must be acknowledged that the personal feedback that the athletes received from their food records may have affected their food intake. Thus, it was not possible to differentiate whether it was the education sessions or the individual feedback that caused the changes in knowledge and food intake.

All the athletes were instructed in how to complete the food diary. They also received a food picture book to help them estimate food amounts. They filled the diary on two weekdays and one weekend day, both at baseline and after follow-up. This combination of days was used in order to find a balance between different types of days across the week and to thus obtain more precise information on absolute food intakes.[140] To detect the intervention-induced changes in food intakes, the diaries were completed on similar days after follow-up. In an ideal situation, a seven-day food record would be used for measuring food intakes, which would reduce the influence of potential misreporting and daily variation in diet which may cause biased results. However, this is not reasonable in many study settings because the amount of work required of the study participants may reduce their compliance.[140] In addition, as the athletes' macronutrient and energy intakes were our main interest, a shorter food record was regarded as being sufficiently capable of detecting average intakes. For smaller nutrition details, longer observation periods would usually be needed.[140] In this study, the focal interest was in the long-term effects on diet, because after all, these matter the most. Therefore, the food diaries were filled at baseline and after the follow-up period. An extra food diary recording immediately after the education sessions could have been regarded by the athletes as an additional burden and may have interfered with the effects of the mobile application use, which included creating a visual food diary using a smart phone.

As food records only give an estimate of food consumption over a few days, under- or over-reporting and self-reporting bias is always a risk.[140] However, it may be assumed that if an individual participant under- or over-reported at baseline, they would also do so after follow-up.[144] Therefore, under- or over-reporting did not really affect the changes in food intakes that were of main interest. Typically, under-reporting is more common than over-reporting.[144] However, the prevalence of under- and over-reporting depends on specific nutrients and the assessment tool in use. People tend to report their diet as slightly healthier than it is in reality. Current research evidence shows that in multiple-day food records, energy intake is typically underestimated by 20–25%. This has been confirmed by comparing food records with doubly-labelled water. The possibility of under-reporting must also be taken into account when interpreting the results of this thesis. In addition, peoples' diets typically vary greatly from day to day and the daily variation of some nutrients is great. This may explain the variances in the food intake data and may reduce the statistical power of the results. The influence of under- or over-reporting could have been detected using biomarkers (e.g. nitrogen in urine to detect protein intake) or doubly-labelled water (energy intake).[140] However, due to the extra burden and high costs of some of these methods, especially doubly-labelled water, we did not use them in this study. In addition, as we wanted to disturb the athletes' training as little as possible, we used no invasive study methods.

## 6.3 Interpretation of results

### 6.3.1 Baseline nutrition knowledge level of athletes and coaches

Several studies have concluded that the nutrition knowledge of athletes and coaches is often inadequate[14,60,62–66] and that coaches tend to have better nutrition knowledge than athletes.[13,14] The current thesis supports these findings. The difference between the knowledge of the athletes and coaches was statistically significant, the coaches having better nutrition knowledge. Although there is no definite score threshold at which knowledge is adequate or inadequate Torres-McGehee et al.[14] suggest that knowledge level is adequate if it is 75% or higher, and many researchers have used this definition. According to this, we can conclude that the coaches' average nutrition knowledge was adequate, as was that of the athletes' in Study III. The average nutrition knowledge scores of the athletes in Study II, on the other hand, were below 75. However, this thesis study did not use this definition. Only focusing on good mean scores would mean neglecting the fact that more than half of the athletes in Study II, 48% of the athletes in study III, and 44% of the coaches in Study II scored below the mean. Some athletes answered only 47% of the items correctly. In addition, the participants who obtained relatively good scores may also have had considerable misbeliefs regarding some of the essential topics of sports nutrition. In conclusion, this kind of questionnaire enables us to observe the general nutrition knowledge level and compare the scores of different study populations completing the same questionnaire, but it is not suitable for comparing the scores of different studies using different tools for assessing the knowledge level.

The difference between the knowledge of the athlete groups in Studies II and III could possibly be explained by the difference in study designs. In Study II, the athletes only needed to volunteer to complete a single questionnaire. In Study III, they were required to attend three education sessions and complete a food diary twice. Therefore, it is possible that the athletes participating in the intervention were more interested in nutritional issues in general than the athletes in Study II.

In Study II, the female athletes achieved significantly better nutrition knowledge scores than the male athletes, and the female coaches significantly better scores than the male coaches. This finding is supported by other studies[60,64,67–69] and has been explained by the fact that women may generally find nutrition and health-related issues more interesting than men.[60,67,69] However, contrary to this, Study III found no significant association between the gender and nutrition knowledge score. This finding is, on the other hand, supported by a systematic review by Trakman et al.[13], which indicated that ten out of 15 studies found no significant difference between men and women's nutrition knowledge scores. Thus, it might not be possible to generalize that women are more interested in nutrition-related issues than men. Among competitive athletes, the urge to succeed and win may increase their interest in sports nutrition, regardless of gender.

There was a significant association between age and nutrition knowledge among both the coaches and athletes of Study II. Among the athletes, nutrition knowledge was positively associated with age: the older the athlete, the higher the nutrition knowledge score. Among the coaches, the association was negative: the younger the coaches, the higher the nutrition knowledge score. Some other studies[60,95] have also found a similar association between athletes' age and nutrition knowledge, and this has been explained as being due to younger athletes possibly finding nutritional issues less relevant than their older peers.[60] Their ability to understand nutrition and health-related issues might also be lower than that of older athletes due to fewer years of education. As an example, Finnish high school students study health education at schools, and the youngest participants of the study may not yet have received this education. The association between coaches' age and nutrition knowledge has varied across studies. A study by Juzwiak and Ancona-Lopez[62] found no correlation between coaches' age and nutrition knowledge scores but in a study by Cockburn et al.[66], the coaches aged 51 and above had significantly better nutrition knowledge levels than the younger coaches. Contrary to these results, in Study II, the younger coaches obtained higher nutrition knowledge scores than the older coaches. In the Finnish coach population, this might be explained as resulting from the increasing emphasis given by coaching education to sports nutrition in recent years. In contrast to Study II, in Study III found no association between athletes' age and nutrition knowledge, or between their main sport and their nutrition knowledge. This may be explained by the relatively narrow age range of the athletes and the somewhat similar demands of different endurance sports in terms of training amounts and nutrient and energy needs. Thus, age and main sport did not confound the results.

The good overall support received by elite athletes and their better access to nutritional resources may have a positive effect on their nutrition knowledge[13]: the athletes of Study II, who were a part of a national team, obtained numerically higher knowledge scores than the athletes who were not a part of such training teams. This has also been confirmed by other studies.[13,15,60]

The participants of Study II were asked to evaluate their own nutrition knowledge. The coaches who regarded their nutrition knowledge as excellent obtained higher nutrition knowledge scores than the coaches who regarded their knowledge as satisfactory. This finding was in line with the results of Cockburn et al.[66] A similar tendency was found among the athletes of Study II, but the differences were not significant. This may be explained as resulting from coaches perhaps being better at evaluating their actual knowledge level than athletes, because of the experience they have gained over time and education years.

As noted in both Studies II and III, the questions on dietary supplements and nutrition recommendations were the most difficult for the athletes. Other studies have also reported that the main gaps in athletes' nutrition knowledge are related to energy density, dietary supplements and proteins[13], which reflects that nutritional misbeliefs are quite similar among athletes, regardless of their place of residence and sport. Among the coaches, the 'Nutrition recommendations for endurance athletes' was the most difficult section. This finding has also been supported by other studies. In a study by Juzwiak and Ancona-Lopez[62], coaches typically overvalued proteins and low-fat diets and emphasized food myths. Among both athletes and coaches, the prevailing protein hype and media visibility of the concept of restricting carbohydrates[41] may have biased their knowledge.

### 6.3.2 Effects of intervention on nutrition knowledge and dietary intake

The nutrition knowledge of the athletes increased statistically significantly during the nutrition education intervention. This increase was significant both one week and three months after the last education session. The knowledge scores were higher in all subsections of the questionnaire, but particularly in the questions on dietary supplements. This was a positive finding because of the already mentioned multiple misunderstandings linked to dietary supplements and their unnecessary use.[17] It is promising that the knowledge regarding dietary supplements can be improved, because it shows that dietary misbeliefs can be altered with science-based education, regardless of the commercial messages and media hype around some specific dietary aspects. Improvements in knowledge scores have also been reported in previous intervention studies of athletes.[88,90,100,103,104,115,117]

One of the main findings of this study was that nutrition knowledge among young athletes increased significantly after three fortnightly 90-minute participatory nutrition education sessions in groups. However, as mentioned earlier, the possible effect of the repetition of the test must be taken into account when interpreting the results, even though it was assumed that actual learning during the intervention rather than completing the same questionnaire three times mostly affected the results. Other researchers have reported significant increases in nutrition knowledge with even shorter total duration of education sessions,[85,90,117] but usually there have been more than three education sessions lasting at least an hour at a time.[88,89,100,103,104,115,120,122] The education should not be too short or simple, as this might not support sustainable results. This was reported by Jacob et al.[85] as they noted that the increased nutrition knowledge after 2x90-minute education sessions was not maintained during the follow-up. The findings of this thesis study mean that even a relatively small use of time and other resources for nutrition education might promote positive changes in nutrition knowledge if the education is structured and motivational. Because these positive changes might benefit athletes in their training, the hope is that this finding will encourage all sports organizations to increase the nutrition counselling they provide.

The education of the intervention was based on SDT, a theory explaining the role of humans' inner resources in personality development and behavioural changes, and the concept of meaningful learning processes, which explains the conversion of real-life challenges into motivating educational challenges.[107,112] The prerequisite for effective learning is an increase in motivation.[107] The aim of the education sessions was to increase this motivation related to nutrition by allowing the athletes to take part in the sessions in the form of discussions, different types of tasks, and goal-setting. Another factor that possibly affected motivation was the personal feedback on the food diaries and the use of the mobile app. These may also have led to better engagement in the intervention and to better willingness to participate in the education sessions. Some previous nutrition interventions for athletes have been based on various behavioural change methods.[103,104] The improvements in nutrition knowledge were also significant in these studies. This is also supported by research showing that behaviour change interventions are most effective when they are based on behaviour change theories.[145] Although the behavioural change theories in the above mentioned studies and the thesis were different, homework and different in-class activities and tasks played an important role in all of them, emphasizing their role in effective learning. Especially when aiming to achieve sustainable changes in dietary behaviour, which was also one aim of this thesis study, traditional nutrition education methods should be combined with behavioural change strategies and the practical skills needed for selecting a desirable diet.[69,100,101]

This importance of combining practical skills and traditional education was taken into consideration in the planning of the content of the mobile app intervention. The tasks and the feedback were planned so that they would affect athletes' motivation. They aimed to make the benefit of dietary changes attractive and to increase confidence in changes being possible.[101] The use of the application also aimed to increase practical sports nutrition knowledge. The mobile app was used regularly by over 80% of the athletes in the EDU+APP group, reflecting that engagement in the application use was high. However, nutrition knowledge did not improve any further among the athletes using the mobile app.

A previous study by Simpson et al. also evaluated the changes in team sport athletes' nutrition knowledge using the same app[123], and observed moderate improvements. The main factor distinguishing the app use in the study by Simpson et al.[123] and the app use in Study III was the utilization of peer support, which was not utilized in Study III, as was explained in the limitations section (Section 6.2.2). Even though peer support is regarded as one of the main benefits of mobile apps, we made a conscious choice to use only the single user mode. As mobile apps have not frequently been used for improving knowledge,[132] it would be worth studying the best way to use them in education and how to involve peer support. The same app has been used earlier for treating patients with DE, other mental health problems or weight issues, for example.[146] However, as these results are only from pilot studies, presented publicly in seminars and workshops, this thesis presents no results regarding their applicability for these purposes. In addition, other apps and social media-based methods have generally been used for mostly dietetic practices[147], such as in the assessment of dietary intake[127] or in the promotion of weight loss.[133] As the quality of different apps and the extent of the theory-based behavioural strategies built inside the apps vary widely[133–135], it is even more important to know the strengths and limitations of different apps and to build interventions in a way that they utilize the chosen app in the best way.

The athletes' energy intakes increased slightly during the intervention. However, they were below the estimated energy expenditures both at baseline and after follow-up. Many other studies have also made this finding.[100,103,119] Self-reporting bias must always be considered in this kind of study setting. The potential underestimations of energy and nutrient intakes may distort the gap between the actual energy intakes and their estimations. Since the athletes' weights increased during the study, the presence of either underreporting or incorrectness of total energy expenditures, or both, must be taken into account. However, it should also be noted that the education sessions were mainly held immediately after the competitive season and that the follow-up period was during the athletes' training season, which may in itself, have had a slight effect on the athletes' weights and eating habits.[148] In addition, the total energy expenditure was also only a rough estimation, as the same physical activity level was used for all athletes, meaning that, gender, weight, height and age were the only distinguishing factors in the TEE estimations. This level was chosen on the basis of the typical training amounts of competitive endurance athletes of this age (after consultation of the main coaches of sports high schools and sports academies), but of course individuals' training habits always vary. However, the same physical activity level was used at baseline and after follow-up, which made the estimations comparable.

The athletes' average intake of carbohydrates was insufficient throughout the study. Average carbohydrate intakes varied from 4.9 $g \cdot kg^{-1} \cdot day^{-1}$ (EDU group at baseline) to 5.4 $g \cdot kg^{-1} \cdot day^{-1}$ (EDU+APP group after follow-up). These only meet the recommendations for low intensity or moderate training (defined as ~1 $h \cdot day^{-1}$) and are not enough for moderate to high intensity endurance training (1–3 $h \cdot day^{-1}$), for which the recommendation is 6–10 $g \cdot kg^{-1} \cdot day^{-1}$.[22] It should be noted that for some of the athletes, training volumes may have been even higher, and recommended carbohydrate amounts could be as high as 8–12 $g \cdot kg^{-1} \cdot day^{-1}$. Considerable changes should be made to athletes' diets to achieve these carbohydrate intakes. They could add juices or carbohydrate drinks or other carbohydrate supplements[26], for example, or eat snacks rich in carbohydrates, such as bread or muesli. However, as mentioned earlier, potential under-reporting must also be taken into account, and it might in part explain some of the inadequacy in the observed low carbohydrate intakes. Supported by the above-mentioned 95% confidence intervals, the carbohydrate intakes of the EDU and EDU+APP groups were 4.4 to 5.5 and 4.9 to

6.0 $g \cdot kg^{-1} \cdot day^{-1}$, respectively. In other words, a notable number of the athletes also had enough carbohydrates (≥ 6.0 $g \cdot kg^{-1} \cdot day^{-1}$) in their diets, even when under-reporting was taken into account. However, even after under-reporting had been acknowledged, the carbohydrate intake of athletes was far from being in the upper range of the recommendations.

Carbohydrate intakes were also compared as percentages of total energy, because under-reporting does not affect these values as much as when they are compared as absolute intakes in grams. The average intakes and their 95% CI were below 50% of total energy, which can be regarded as somewhat low for competitive endurance athletes. Many of the athletes' carbohydrate intakes were sufficient, but on the other hand, some athletes' intake was considerably below the mean. The quality of carbohydrate sources in the athletes' diets can be regarded as good, as their mean fibre intakes (32–38 $g \cdot day^{-1}$) exceeded the Nordic nutrition recommendations (25–35 $g \cdot day^{-1}$)[39] as well as the estimates of the Finnish adult population average (woman: 20 $g \cdot day^{-1}$; men 22 $g \cdot day^{-1}$).[41] If the carbohydrate intake values were too low due to under-reporting, then the average intake of fibre was, in reality, even higher. Other studies among athletes have reported fibre intakes below recommendations.[100,103] The average intake of fats (1.4–1.6 $g \cdot kg^{-1} \cdot day^{-1}$) met the recommendations for endurance athletes (1–2 $g \cdot kg^{-1} \cdot day^{-1}$) throughout the intervention. In the EDU+APP group, the average intake of proteins (1.9–2.1 $g \cdot kg^{-1} \cdot day^{-1}$) was in the upper range of the recommendations (1.5–2 $g \cdot kg^{-1} \cdot day^{-1}$) throughout the intervention and slightly above them after follow-up.[26] It seems reasonable to suggest to athletes that they slightly reduce their protein intake and replace it with carbohydrates if the aim is to increase carbohydrate intake but not total energy intake.

Simply giving information and increasing knowledge does not always turn into the desired behaviour if the intention to perform the behaviour is lacking.[102] This might be one of the reasons why the changes in the athletes' nutrient and energy intakes were only minor, even though their nutrition knowledge improved significantly. This has also been noted in other interventions.[100,149] Knowledge is not the only factor that explains what we eat. Some factors are related to lifestyle and beliefs, others are psychological, economic and social, or environmental determinants of food choices.[15]

Many of the athletes in the intervention also knew already at baseline how to eat according to nutrition recommendations. This was reflected by the finding that the mean nutrition knowledge scores were on a satisfactory level already before the education sessions. This probably left less room for improvements in the athletes' diets. The athletes may have been unwilling to make changes to their diets if their knowledge was already fairly good and they therefore thought that they did not need to change anything. However, the diets of the athletes were better than that of the general Finnish population[41] already before the study, which may have made the possible changes in diet small and not very visible. Insufficient carbohydrate intakes and notable intakes of proteins among many athletes may also be the result of food choices reflecting the prevailing hype around protein and the restriction of carbohydrates.[41]

## 6.4 Applicability of results to other sports and age groups

The participants of this thesis' sub-studies were young (16–20 years) Finnish endurance athletes (Studies I–III) and their coaches (Studies I–II). An Australian study found no significant differences between the nutrition knowledge of individual athletes or team sport athletes on either national, junior or open international levels.[60] Other studies have also failed to find any significant differences between the nutrition knowledge of coaches of 'leanness sports' (e.g. gymnastics and cheerleading) and 'non-leanness sports' (e.g. football)[81] or of coaches of gymnastics, tennis, judo and swimming.[62] Thus, we can conclude that there are no differences between team sport and individual sport coaches' nutrition knowledge. Therefore, as no differences have previously been found, the results of this thesis study were compared with those from other nutrition knowledge studies of athletes and coaches, regardless of their sports disciplines. For the same reason, it could be acceptable to consider that the results of this thesis study are generalizable not only to individual endurance athletes or their coaches but also to athletes of the same age from other sport disciplines or to team sport coaches.

As the older athletes in Study II obtained higher nutrition knowledge scores, the results of this thesis study are probably not as such applicable to children and adolescent athletes younger than 16. Nutritional issues probably appear less relevant to younger athletes, which explains the lower scores of the younger athletes than those of the older athletes.[60,95] In addition, adults probably provide most of the food for athletes under the age of 16. The younger the athletes are, the less education years they have completed, which may lower their ability to understand nutritional issues. In addition, the opportunities for nutrition education are probably less among younger athletes, as they are not yet in sports high schools or training groups for talented athletes. As the participants of Studies II and III were young adults of the mean age (18 years), it can be assumed that these study results also apply to other adult athletes. However, it should be borne in mind that the longer the athletes have been competing on a high level, the better their nutrition knowledge probably is due to their longer access to nutritional resources and good overall support.[13]

The questionnaire was designed in accordance with the typical steps for creating questionnaires so that most of its items concerned general nutrition recommendations and sports nutrition knowledge irrespective of the target group of the questionnaire.[13] However, to obtain results that would be even more applicable to a specific sports discipline other than endurance sports, some questionnaire items could be fine-tuned. The present questionnaire had 16 items that mentioned endurance athletes and five items that clearly focused on long-duration exercise. However, even some of the items that mentioned endurance athletes could be generalized to all other athletes. Therefore, with only slight changes in the wording of the items, using this questionnaire with athletes and coaches other than those in endurance sports would probably result in fully comparable knowledge scores.

## 6.5 Practical implications of the results

This study revealed athletes' and coaches' gaps in nutrition knowledge and thus enables the planning of more targeted, effective nutrition education programmes and education interventions in the future.[77] The results of this study can be used for various educational purposes among both coaches, and athletes, and probably also their parents, even though the latter is only an assumption as it is not based on the results of this thesis study. One of the most obvious targets for such information is coaches' education, in which the amount of nutrition education is currently very limited. Athletes' nutrition education in sports high schools, training groups and sports clubs can also be improved and targeted at their needs, based on these results.

The questionnaire can be used in schools, sports clubs or federations for pre-analysing the nutrition knowledge of athletes, parents, coaches and other athletic staff members. In addition to determining their knowledge level, the information can be used for planning whether they need more nutrition education and what its focus areas should be.

In Study III, significant and sustainable improvements in nutrition knowledge were only seen after three education sessions, which were pre-tested and carefully designed on the basis of psychological theories and acknowledged the target population's needs. Hopefully, the finding of relatively time- and cost-efficient but simultaneously effective nutrition education will encourage sport clubs and organizations to increase the nutrition counselling given in groups and by a nutrition expert. When the counselling is held in groups, participants receive peer support and the coach's resources can be better directed to the coaching itself. The role of a nutrition expert is significant for two reasons: first, to emphasize the role of nutrition in sports and to simplify consulting a dietitian or other nutrition expert; and second, to also educate the coaches and subsequently reduce their biased nutrition counselling, as studies have found that even coaches with poor nutrition knowledge tend to make nutrition recommendations to athletes and are among their main sources of nutrition knowledge.[14,83]

In Study III, athletes' energy intake, especially in the form of carbohydrates, was below the recommendations throughout the intervention. This may have an adverse effect on their performance, recovery and health. Other athletes can also use this information and try to increase their carbohydrate and subsequent energy intakes, if in any doubt of their adequacy, as they are presumably likely to be too low than too high. Coaches should help and encourage athletes to make such changes in their diets. A mobile app could be used to increase carbohydrate intake, even though we saw no significant changes in the EDU+APP group's dietary intake in our study. Regardless of this, several athletes in the group commented that using the app had improved their motivation and helped them make dietary choices.

## 6.6 Implications for future studies

This was the first study to evaluate the nutrition knowledge of young Finnish athletes and their coaches. Therefore, using the same questionnaires as such, or with adjustments could produce comparable, interesting results regarding the level of nutrition knowledge in different fields of sports. As an example, if athletes and coaches in a particular field of sports scored considerably better than those in other sports fields, the nutrition education models of that sport could also be utilized in other sports.

Obtaining up-to-date information on athletes' and coaches' nutrition knowledge is important. However, in addition to coaches, parents are among the most important sources of nutrition information and guidance for children.[2] Despite this, very little research has been conducted on parents' nutrition knowledge. Parents' limited nutrition knowledge may considerably affect their children if parents compile the family's grocery shopping. In this case, despite their nutrition knowledge level, athletes may need to make nutritional compromises that do not optimally support their athletic career. Therefore, conducting a study similar to Study II would provide useful information on whether the sports nutrition education of parents should be increased and improved.

In this study, the use of a mobile app did not further improve the athletes' nutrition knowledge or nutrient intake. Whether the mobile app in this study was used in the best way possible for improving learning remains undetermined. However, it should be noted that in this study, only one app was used and, therefore, the results do not prove that other approaches either with other apps or different uses of the same app would not be beneficial. Future studies should examine the benefits of mobile apps in individual athletes' nutrition education to determine the best practices for providing effective nutrition counselling utilizing modern technologies.

It is known that good nutrition knowledge can be positively associated with athlete's dietary behaviour and subsequent dietary intake.[69] However, knowledge is only one of the variables behind changes in this behavior, and more research is needed on how to develop athletes' and coaches' nutrition education in order to close the gaps in knowledge and transfer the improved knowledge into improved dietary behaviour. Finding how to improve athletes' energy and carbohydrate intakes is especially important.

# 7 Conclusions

This was the first study to measure the nutrition knowledge of young Finnish endurance athletes and their coaches. In this study, enhancing athletes' nutrition knowledge and dietary intakes were of great interest due to the well-known fact that nutrition plays a central role in athletes' performance, recovery, health and development. A nutrition knowledge questionnaire was created and validated as part of this study, both for collecting information on nutrition knowledge and for using this information when creating an effective education plan aiming to improve athletes' nutrition knowledge and dietary intakes.

This study showed that nutrition knowledge was relatively low among the athletes and highly variable among both the athletes and coaches. The dietary supplement and nutrition recommendation-related items seemed to be especially difficult for the athletes. The coaches also had difficulties answering the questions on nutrition recommendations for endurance athletes. The mean nutrition knowledge scores were higher among the coaches than among the athletes. The identification and utilization of the information on the athletes' knowledge gaps enabled the planning of an education intervention that was able to focus specifically on the special needs of the athletes.

The nutrition knowledge of the athletes improved significantly during the nutrition education intervention. However, contrary to our hypothesis, the use of a mobile app as an education instrument did not further improve this knowledge: regardless of the improved nutrition knowledge, only minor changes were detected in the athletes' dietary intakes. The mean carbohydrate intake was below the recommendations throughout the intervention and the mean energy intake was below the estimated mean energy expenditure. However, the nutritional quality of the athletes' diet was better than that of the general Finnish population.

In summary, this study showed that significant, long-term improvements to nutrition knowledge among athletes are possible after only three education sessions and the completion of two food diaries with feedback. Nutrition education can promote significant improvements in nutrition knowledge when the education is carefully designed on the basis of psychological and educational theories and it acknowledges the target population's needs. Such cost- and time-efficient nutrition counselling should be easy to incorporate into sports clubs' and sports organizations' agendas.

# Acknowledgements

Four years ago, I was baking cakes for my athlete's confirmation party. Earlier that summer I had been thinking about starting a PhD project in sports nutrition. However, the planning was only in its infancy. Who would have known back then that these cakes would spark my whole thesis? At the party, a man, who would become my future supervisor, praised my baking, and as we talked, he told me all about his ideas connected to nutrition, sports and related mobile apps. When my previous ideas and plans were combined with his ideas, the whole frame for the thesis suddenly emerged.

My passion for assessing nutrition knowledge and skills among athletes and coaches started from a real-life problem. As a cross-country skiing coach, I had noticed that a multitude of athletes and coaches had really limited knowledge of sports nutrition. The same misunderstandings and gaps in knowledge were repeated over and over in their discussions. I also noticed that some sport federations arranged coach education in which not a single word addressed nutrition. I knew that, as the coach of a local skiing club, I could only help a limited number of athletes. But I wanted to do more. The bright idea in my mind that my research could enable me to help a much larger number of athletes and coaches increased my passion for this project.

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The years with this thesis have been the best but also the hardest of my life. Working in academia with my own, interesting project really motivated me. I found a passion for giving lectures to athletes and studying their food diaries and I really felt like I could help people with my research. So-called academic freedom also enabled me to fill all my free time with coaching. Being in the sporting world enabled me to meet new people who were valuable contacts for the thesis. On the other hand, there were times when I was extremely tired and stressed and ready to quit the whole project. Luck was not always on my side either. During this project, I managed to break my shoulder and suffer from terrible back pains. However, even a broken shoulder and two back operations did not pull me down; they only served to give me extra motivation to complete this project in good time.

Now the thesis is done, and it is time to celebrate and bake some cakes again. Who knows where they will lead me this time?

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# Appendices

## Appendix 1. The nutrition knowledge questionnaire (papers I, II & III)

UNIVERSITY OF HELSINKI

Dear young athlete!

Please answer the following questions. Circle the correct answer/answers or write your answer on the line. All of the information obtained in the survey will be treated confidentially and anonymously.

**Background information:**

1. Sex: a. male
   b. female
2. Date of birth: ____.____.________
3. Height: ________ cm
4. Weight: ________ kg
5. I live: a. With my parents/parent
   b. Alone
   c. With someone else, whom?
   ___________________________
6. Are you taking any regular medication? If yes, what?
   ___________________________________________________
7. Do you have food allergies or are you on a special diet, and if so, what kind of diet?
   ___________________________________________________
8. Your field of sport:
   ___________________________________________________
9. Your most significant individual achievement in your sports (placing, year):
   ___________________________________________________
10. Are you part of any team coaching group of your main sport? Name the group.
    ___________________________________________________
11. What is your own idea of the level of your nutrition knowledge (use a school grade from 4 to 10): ________

Dear young athlete!

Please answer the following questions. Each statement is either true or false, and you must choose the alternative that you believe to be correct. Please be true to your own knowledge instead of trying to “guess what would be right”. All information obtained in the survey will be treated confidentially and anonymously.

| | **Nutrition recommendations for endurance athletes** | **T**<br>true | **F**<br>false |
|---|---|---|---|
| 1 | Healthy nutrition is more important for an athlete during the competition season than during the off season. | | |
| 2 | An athlete who aims for the top must pay as much attention to diet as to training and rest. | | |
| 3 | Basic everyday food does not meet the nutritional needs of an endurance athlete who consumes a lot of energy. | | |
| 4 | Occasional unhealthy food choices have an effect on endurance athletes’ performance. | | |
| 5 | Keeping a consistent eating rhythm is easiest when the routines are similar from day to day. | | |
| 6 | Carbohydrates are the most important energy source in endurance sports. | | |
| 7 | Products with added sugar are not suitable for endurance athlete’s diet. | | |
| 8 | An athlete who is following a healthy diet must cut down on all sweet and salty treats (e.g. sweets and chips). | | |
| 9 | Sugar is a carbohydrate. | | |
| 10 | An endurance athlete’s carbohydrate requirement can be more than twice that of a physically inactive person of the same age, sex and weight. | | |
| 11 | Carbohydrates contain more energy per gram than fat. | | |
| 12 | Dietary fibre is an indigestible (not absorbed in from the gut) carbohydrate. | | |
| 13 | It is not advisable to use frozen vegetables, because their nutritional quality is much lower than that of fresh vegetables. | | |
| 14 | Carbohydrates contain as much energy per gram as proteins. | | |
| 15 | It is advisable to eat high amounts of protein because excess protein furthers muscle growth. | | |
| 16 | Endurance sports do not increase the daily requirement for protein. | | |
| 17 | Endurance athletes often have trouble getting enough protein from a regular diet. | | |
| 18 | It is not possible to get enough protein from vegetarian food. | | |
| 19 | Excess protein in the body is stored in the muscles. | | |
| 20 | It is advisable to consume protein at every meal and snack. | | |
| 21 | The quality of animal protein is higher than that of plant protein. | | |
| 22 | It is possible to get too much protein from one’s diet. | | |
| 23 | A fatty diet is favourable for endurance athletes, especially during the competition season. | | |
| 24 | Consuming fatty food leads easily to weight gain. | | |
| 25 | All animal fats are unhealthy. | | |

| | | T<br>true | F<br>false |
|---|---|---|---|
| 26 | Coconut oil is a good fat source for an endurance athlete. | | |
| 27 | Nuts contain a high amount of unsaturated fat. | | |
| 28 | Butter is a good fat source as it does not contain any food additives. | | |
| 29 | An endurance athlete should prefer low-fat dietary products. | | |
| 30 | The vitamin and mineral requirements of an endurance athlete are so high that it is difficult to meet this need by following a regular diet. | | |
| 31 | Iron deficiency worsens the delivery of oxygen to the muscles. | | |
| 32 | Iron deficiency weakens the immune system and has a negative effect on performance. | | |
| 33 | Female athletes need more iron than male athletes. | | |
| 34 | Food with a high amount of vitamin C reduces the absorption of iron. | | |
| 35 | Fatty milk products contain more vitamin D than skim milk products. | | |
| 36 | Vitamins provide energy. | | |
| 37 | Magnesium deficiency is common among endurance athletes. | | |
| 38 | High doses of vitamins and minerals can be harmful. | | |
| 39 | Vitamins and minerals are only obtained from fruits, berries and vegetables. | | |
| 40 | Red meat is an excellent source of iron. | | |
| 41 | The best way to avoid cramps is to use magnesium supplements. | | |
| 42 | An endurance athlete should use iron supplements regularly. | | |
| 43 | Exercising in the morning before breakfast helps to reduce the body’s fat stores. | | |
| 44 | There is no use for a decent meal after a late evening training session. A light snack is enough. | | |
| | | | |
| | **Dietary supplements** | | |
| 45 | Athletes should take dietary supplements because exercise increases nutrient needs. | | |
| 46 | Using dietary supplements reduces the need for rest and exercise. | | |
| 47 | The use of dietary supplements is associated with the risk of violating an antidoping rule. | | |
| 48 | Caffeine can improve endurance performance. | | |
| 49 | For an athlete who is aiming for the top, it is advisable to take dietary supplements. | | |
| | | | |
| | **Fluid balance and hydration** | | |
| 50 | An athlete should drink during exercise only when he/she is thirsty. | | |
| 51 | Juice is a good drink choice during exercise. | | |
| 52 | Thirst is an adequate sign of performance-impairing dehydration. | | |
| 53 | An endurance athlete needs daily protein drinks or other protein products during the competition season. | | |
| 54 | Water is the best drink choice after a long competition (>2 h). | | |

| | | T<br>true | F<br>false |
|---|---|---|---|
| 55 | During a long performance, it is advisable to drink only sugar-free sport drinks. | | |
| 56 | Beer is a good workout recovery drink. | | |
| | | | |
| | **Energy intake and recovery** | | |
| 57 | Whole grain products rich in fibre are a preferable carbohydrate source, even in situations where fast energy supplementation is needed. | | |
| 58 | Fat contains high amounts of energy, and therefore, athletes should eat fatty foods before competitions. | | |
| 59 | It is not advisable to drink beverages with a high sugar concentration during a competition. | | |
| 60 | It is advisable to eat a big meal right before long-lasting exercise. | | |
| 61 | Nuts contain a lot of energy and are therefore a good energy source during high-intensity exercise. | | |
| 62 | An athlete can maintain his/her level of performance during long-lasting exercise by consuming fast absorbable carbohydrates. | | |
| 63 | During a very long competition, it is advisable to use a sport drink containing salt. | | |
| 64 | The food eaten prior to exercise has no effect on recovery. | | |
| 65 | Special products (e.g. protein bars) enhance recovery better than regular food because of their balanced nutrient ratios. | | |
| 66 | The replenishing of energy stores takes place most effectively immediately after exercise. | | |
| 67 | Consuming fat after exercise enhances recovery. | | |
| 68 | A sport drink with added vitamins enhances recovery more than a drink without added vitamins. | | |
| 69 | Alcohol slows down recovery from sport. | | |
| 70 | The training benefits are lost if an athlete does not eat immediately after engaging in sport. | | |
| | | | |
| | **Association between food choices and body image** | | |
| 71 | If an endurance athlete aims at losing weight, he/she should cut all carbohydrates from his/her diet. | | |
| 72 | A low carbohydrate diet is the easiest way to build muscles in an athlete. | | |
| 73 | The easiest way to manage weight is to eat only a couple of times a day. | | |
| 74 | Fast weight loss always takes place mainly in the fat tissue. | | |
| 75 | It is difficult to increase muscle mass during weight loss. | | |
| 76 | Muscle growth is enhanced when the amount of dietary fat is kept as low as possible. | | |
| 77 | Irregular periods can be due to hard training or low dietary energy supply. | | |
| 78 | Weight loss enhances performance. | | |
| 79 | Eating too little can have adverse effects on hormone metabolism. | | |