Peri-Exercise Nutrition: An Innovative Approach to Dietary Assessment in Trained Populations

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A thesis submitted to the University of Limerick in fulfilment of the requirements for the degree of Doctor of Philosophy

University of Limerick

Supervisors
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Submitted to the University of Limerick, March 2020
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Abstract

This thesis offers peri-exercise nutrition (PEN) advancements to dietary assessment for trained populations. The PEN approach promotes time-specific dietary data collection, analysis and prescription, places exercise stimulus as a key consideration of dietary support that is aligned with the goals of trained populations. Engaging the PEN model required advancing data collection and analysis methods.

The application of PEN as an advancement to the traditional dietary method of assessment was examined in the context of nutrient support to resistance training (RT) adaptation in a group of trained-individuals, and also nutrient support to endurance exercise adaptation and performance of endurance-trained individuals. Subsequently, traditional and PEN methods were used to apply dietary standardisation to a nutrient-exercise intervention study. Cross-sectional assessment of habitual dietary intake was undertaken on (1) a convenience sample of 37 resistance-trained males (18–40 years) with at least six months of continuous RT experience (RT ≥ 3 h·wk⁻¹), and (2) a case study of three endurance-trained males (18–45 years) with VO₂max ≥ 55 ml·min⁻¹·kg⁻¹, and participating in competitive endurance events.

Traditional dietary analysis demonstrated that, on average, resistance-trained males failed to meet carbohydrate intake recommendations. The PEN analysis revealed that consumption of protein one hour pre-, during RT and one hour pre-bedtime was not common practice. However, though participants consumed [Mdn (25th–75th percentiles)] 5 (4–6) EO post-RT, protein intake per EO was non-optimal in 44% of reported EO (N = 608) post-RT. Overall distribution of EO could be improved in 71% of instances (N = 402) post-RT. The traditional dietary analysis of three endurance-trained males illustrated that daily energy availability and macronutrient intake requirements were met on 0–4 days within a 7-day record. Additionally, the PEN analysis demonstrated that subjects tended to reduce carbohydrate intake before the first endurance training (ET) of the day. Carbohydrate intake recommendations four hours before and during a single competition event were met. In a nutrient-exercise intervention study, a standardised meal plan employing the PEN approach resulted in high compliance to daily quantity of energy and macronutrient intakes [100 (99–100)%, frequency [100 (100–100)%, time and distribution [97 (93–100)%] of EO consumed among resistance-trained males.

Informed by the current evidence-base, the PEN assessment in this thesis demonstrates patterns and adequacy of nutrient intakes specific to exercise and intent of trained individuals. Hence, the PEN approach may be a valuable advancement to traditional methods of dietary assessment. Further research is warranted to digitalise data collection and automate analysis of the PEN approach, as well as to consolidate the benefits of this approach in larger cohorts with more complex exercise paradigms.
Author’s Declaration

This work is presented in fulfilment of the requirement for the degree of Doctor of Philosophy. I hereby declare that the work contained within this thesis is my own work, and was completed with the counsel received from my supervisors. This work has not been submitted to any other university of higher education institution, or for any other academic award within the university. Where the use has been made of the work of other people it has been fully acknowledged and referenced.

________________________________________

Marta Kozior

March 2020
List of Publications and Conference Presentations

List of publications


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Standard Conference Presentation


Poster

Acknowledgements

Thank you for support from funders (Food for Health Ireland), supervisors, colleagues, participants, department academics and support staff, support staff at Nutritics© (Ireland) and also my family and friends.

I would first and foremost like to acknowledge my academic supervisors Doctor Catherine Norton and Professor Philip M Jakeman for their support, advice, time dedicated to mentorship throughout and opportunities provided during the research programme.

I wish to acknowledge Hilkka Kontro, Doctor Robert Davies and Doctor Brian Carson for shared knowledge and expertise in exercise physiology, and students (in particular Clodagh Murphy), who assisted with the dietary data management.

I also wish to acknowledge colleagues and friends at the University of Limerick. Your shared knowledge, time, encouragement and friendship were invaluable.

To my family, especially my parents and my brother for support, empathy, encouragement, presence and love.

Lastly, to my friends for friendship and your presence.
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<tr>
<td>1RM</td>
<td>1 Repetition maximum</td>
</tr>
<tr>
<td>4E-BP1</td>
<td>Eukaryotic initiation factor 4E-binding protein 1</td>
</tr>
<tr>
<td>AI</td>
<td>Adequate Intake/s</td>
</tr>
<tr>
<td>AKT</td>
<td>Serine/threonine-specific protein kinase</td>
</tr>
<tr>
<td>AOAC</td>
<td>American Association of Analytical Chemists</td>
</tr>
<tr>
<td>CD</td>
<td>Competition day/s</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>DRI</td>
<td>Dietary Reference Intake/s</td>
</tr>
<tr>
<td>DXA</td>
<td>Dual-energy X-ray absorptiometry</td>
</tr>
<tr>
<td>EA</td>
<td>Energy availability</td>
</tr>
<tr>
<td>EAA</td>
<td>Essential amino acids</td>
</tr>
<tr>
<td>EAR</td>
<td>Estimated Average Requirement/s</td>
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<tr>
<td>EEE</td>
<td>Exercise energy expenditure</td>
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<td>EO</td>
<td>Eating occasion/s</td>
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<td>ET</td>
<td>Endurance training</td>
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<tr>
<td>FFM</td>
<td>Fat-free mass</td>
</tr>
<tr>
<td>HMB</td>
<td>β-hydroxy-β-methylbutyrate</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>Mdn</td>
<td>Median</td>
</tr>
<tr>
<td>MPS</td>
<td>Muscle protein synthesis</td>
</tr>
<tr>
<td>mTOR</td>
<td>Mammalian target of rapamycin</td>
</tr>
<tr>
<td>N/A</td>
<td>Not applicable</td>
</tr>
<tr>
<td>NEAA</td>
<td>Non-essential amino acid/s</td>
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<tr>
<td>p70S6K</td>
<td>p70 ribosomal protein S6 kinase</td>
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<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
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<tr>
<td>RD</td>
<td>Rest day/s</td>
</tr>
<tr>
<td>RDA</td>
<td>Recommended Dietary Allowance/s</td>
</tr>
<tr>
<td>RPE</td>
<td>Rating of Perceived Exertion</td>
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<tr>
<td>RT</td>
<td>Resistance training</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SE</td>
<td>Standard error</td>
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<td>SOP</td>
<td>Standard operating procedure</td>
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<td>Abbreviation</td>
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<tr>
<td>TD</td>
<td>Training day/s</td>
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<tr>
<td>TEI</td>
<td>Total energy intake</td>
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<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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<tr>
<td>VO(_{2})max</td>
<td>Maximal oxygen uptake</td>
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Glossary

0 kcal fluid—water or energy-free fluid consumed in isolation (not with an energy containing item) that does not provide energy (0 kcal). Fluid intake (0 kcal) with other energy-containing food, fluids and/or dietary supplements is part of other EO categories, such as main meal, snack or alcoholic beverage.

0 kcal dietary supplement—a dietary supplement is defined as “a food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit” (Maughan et al. 2018). Only a dietary supplement (0 kcal) consumed alone or with 0 kcal fluid should be included in this category. If a consumed supplement contains > 0 kcal or is consumed alongside energy-containing food and/or fluids it should be classified under one of the EO categories. Examples of products that are classified as EO and not supplements due to their contribution of energy include fish oils, spirulina powder, lecithin powder, acai powder, protein powder etc.

Alcoholic beverage—a single EO that contains alcohol only. An alcoholic beverage consumed with other fluids (0 kcal) is classified under this category. Alcohol consumed with energy-containing food, fluids and/or dietary supplements is a part of other EO categories that include main meals or snacks.

Competition day—type of day, during which a competitive event (e.g. race) was reported, i.e. when a trained individual or an athlete competed against other trained individuals or athletes.

Distribution of EO—range of time between two adjacent EO over the course of the assessed time. The distribution between the two EO is assessed if two EO are not separated by sleep time.

Distribution of nutrient intake—range of time between intakes of the same nutrient from food, fluids and dietary supplements, over the course of the assessed time. The distribution between intakes of the same nutrient is assessed if two EO are not separated by sleep time.

Eating occasion (EO)—an intake of energy-containing (> 0 kcal) food, fluids, including alcoholic beverages, and dietary supplements within a discrete, 30-minute timeframe. In a traditional dietary assessment, an EO can be classified either as main
EO (breakfast, lunch and dinner), snacks, pre-sleep snacks or alcoholic beverages. Classification depends on the energy intake and time of intake. In the PEN approach, pre-defined eating terminology as used in traditional dietary assessment, e.g. main EO and snacks, are not used. Instead, the time of intake of food, fluids and dietary supplements is referenced. The time of an EO together with the time of an exercise session are used to calculate the proximity of energy and nutrient intakes to exercise session.

**Frequency of EO**—number of occurrences of EO consumed within the assessed time.

**Frequency of nutrient intake**—number of occurrences of nutrient intake within the assessed time.

**Intensity of exercise**—self-rated perceived exertion using Rating of Perceived Exertion Scale (Borg’s scale) from 0 (rest) to 10 (maximal exertion), 30 minutes post-exercise (Borg 1982; Foster et al. 2001).

**Individual’s intent**—self-reported short, medium and long-term goals of individual while engaging in exercise programme (e.g. body composition, training adaptation and competitive performance-related intent).

**Main EO**—an EO with the highest energy intake consumed 6:00–11:00 is classified as breakfast, 11:01–15:00 lunch, 15:01–22:00 dinner (excluding alcohol consumed exclusively). Alcohol is classified as part of this category when it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.

**Peri-exercise nutrition (PEN)**—assessment of habitual food, fluids and dietary supplement intakes in proximity to an exercise session and in support of an individual’s intent. The PEN approach promotes time-specific, exercise- and intent-orientated dietary assessment and optimised energy and nutrient intake practices for trained individuals within a weekly microcycle. The rationale for the PEN assessment is based on the evidence that in particular scenarios, nutrient intakes in proximity to an exercise session (training or competition) strengthen the outcomes of daily and within-a-day nutrient provision in achieving individual’s goals (Thomas et al. 2016).

**Phase**—a timeframe or duration of dietary assessment before, during and/or after an exercise session, within the PEN approach.
Phase of season—self-reported phase of season by an individual (i.e. pre-season in-season, off-season, injured, rehabilitation or not applicable in non-competing trained-individuals).

Pre-sleep snack—a snack consumed 0–1 hour before bedtime.

Quality of nutrient—a term specific to the assessed nutrient, e.g. protein, carbohydrate.

Quantity of nutrient—a value, dose or amount of nutrient consumed from food, fluids and dietary supplements, within a given time, e.g. per EO, daily.

Rest day—type of day during which no exercise of any type is reported (except for activities of daily living, e.g. housework).

Snack—each EO consumed between the main EO; intake of energy-containing (> 0 kcal) food, fluids and dietary supplements. Alcohol is classified as part of this category if it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.

Time of EO—in data collection, data coding and in traditional dietary analysis it is a time of EO consumed during a day. In PEN analysis, time of EO refers to the proximity to an exercise session.

Time of nutrient intake—in data collection, data coding and in traditional dietary analysis it is a time of nutrient intake from food, fluids and dietary supplements during a day. In PEN analysis, time of nutrient intake refers to the proximity to an exercise session.

Traditional dietary assessment—daily and per EO dietary assessment of habitual food, fluid and dietary supplement intakes.

Training day—type of day that involves a voluntary exercise session (e.g. resistance, endurance, skill-based, team training), which is planned, structured and performed with a particular objective (e.g. maintain physical fitness, improve performance, improve body composition) (Caspersen et al. 1985).

Type of EO—breakfast, lunch, dinner, snack, pre-sleep snack, and alcoholic beverage.

Type of nutrient—a nutrient referred to in dietary assessment and prescription (e.g. a macronutrient, a micronutrient).
Chapter 1

Introduction
1.1. Background

Sport and exercise nutrition has evolved towards a personalised and periodised approach, offering strategies to athletes (from recreational to elite) that optimise training diets to support distinct training stimuli. There is general consensus that this dietary optimisation can enhance training adaptation and athletic performance (Thomas et al. 2016; Jeukendrup 2017; Stellingwerff et al. 2019). Sport and exercise practitioners appreciate the potential enhancements arising from these strategies on athletes’ dietary and training programmes within microcycles mesocycles and macrocycles (Close et al. 2019), which could in turn enhance performance. Dietary recommendations tailored to training programmes and competitive events should promote better understanding of individuals’ dietary practices and motives in proximity to training or competition. However, although dietary requirements for a trained population are dissimilar to the requirements for a non-trained population, the same dietary assessment methods have been used for both populations. Moreover, traditional dietary assessment does not support investigation of dietary practices in proximity to training or competition. Therefore, the overarching aim of this thesis is to address the gap between dietary requirements for individuals engaged in training programmes and competitive events and the methods used to assess those dietary practices.

This thesis proposes an advanced approach to methods of dietary assessment among trained individuals according to the scientific evidence of optimal nutrient practices, termed peri-exercise nutrition (PEN). This approach is not intended to replace traditional dietary assessment, but rather to be used in tandem, to allow practitioners engaging with exercising individuals to place exercise stimuli at the core of dietary assessment. The role of PEN is to bridge the gap between required nutrient intakes to promote training adaptation and sports performance, and assessment of habitual dietary practices of trained individuals in proximity to training and competition. The PEN approach promotes time-specific and intent-orientated dietary assessment, and scientific evidence-based dietary prescription for trained populations. Furthermore, the PEN approach advocates for investigation of nutrient type, quantity, time, distribution,
frequency and quality, which are traditionally not assessed peri-exercise, but required, according to the literature.

1.2. Research Context
This research thesis was funded by Food for Health Ireland and supported by Enterprise Ireland (http://www.fhi.ie/). The research presented in this thesis aligns with the Performance Nutrition work conducted by the research team in the Department of Physical Education and Sport Sciences at the University of Limerick. As research specific to resistance and endurance types of training, this work has recognised that traditional dietary assessment methods are not effective to investigate the diet and exercise-related practices of trained individuals in the context of the adequacy of dietary intake to support training adaptation and sports performance. To address these shortcomings, the author advanced existing methods in dietary assessment. As an example, the author applied traditional and PEN methods of dietary assessment to examine dietary practices of resistance-trained and endurance-trained individuals against established, evidence-based optimal nutrient prescriptions in support of individuals’ intent.

1.3. Research Aims
The primary aim of this thesis is to offer PEN advancements to dietary assessment for trained populations. Advancements to traditional dietary assessment as proposed by the PEN approach (data collection, assessment and prescription) were examined with resistance-trained and endurance-trained males. Therefore, to fulfil this aim, the following objectives were to

1. Provide an overview of existing dietary assessment methods and develop data collection and analysis methods of trained populations (Chapter 2).
2. Investigate evidence-based dietary recommendations in support of trained individuals’ goals while engaging in resistance and endurance exercise (Chapter 4 and Chapter 6).
3. Examine the patterns and/or adequacy of energy and nutrient intakes among resistance-trained males using traditional and PEN dietary assessment methods (Chapter 5).
4. Examine the patterns and/or adequacy of energy and nutrient intakes among endurance-trained males using traditional and PEN dietary assessment methods (Chapter 7).

5. Standardise dietary control during a nutrient-exercise intervention study, by considering dietary recommendations peri-resistance training, habitual dietary practices and food preferences of resistance-trained individuals (Chapter 8).

6. Summarise the current status, challenges and future work of the PEN approach, based on the research study analysis offered in this thesis (Chapter 10).

1.4. Thesis Structure

This thesis is presented in ten chapters. This thesis begins with an introduction chapter (Chapter 1) to present the background, research context, aims and structure of the research studies discussed in the subsequent chapters. Chapter 2 discusses methods of dietary assessment and their use in the context of dietary guidelines. Chapter 2 introduces the PEN approach in the context of data collection, coding, analysis, evidence-based recommendations and the approach complexity. Data collection was based on 7-day dietary- and exercise programmes-related information to represent the habitual practices of athletes within a weekly microcycle. Advancements were made to an existing nutrition analysis platform to code data collected, and therefore, to facilitate analysis. Additionally, Chapter 2 introduces the use of the PEN approach in the dietary prescription and standardisation. Chapter 3 explains common methods used in this thesis. Chapters 4 and 6 demonstrate evidence-based reviews of the dietary intake specific to resistance (Chapter 4) and endurance (Chapter 6) training in support of individuals’ goals.

Two data chapters, Chapter 5 and Chapter 7, examine the patterns and adequacy of nutrient intakes using traditional and PEN dietary assessment methods among resistance-trained (Chapter 5) and endurance-trained (Chapter 7) males. Chapter 5 offers the PEN analysis for the first time. The PEN analysis was specific to resistance training and individuals’ aim. Chapter 7 presents case study dietary analysis of three endurance-trained males. This study revealed multiple aims specific to diverse exercise sessions. The evidence-based dietary recommendations reviewed in Chapter 4 and Chapter 6 were applied to the analyses in Chapter 5 and Chapter 7, respectively. The correction of suboptimal dietary practices is also discussed, where appropriate.
Chapter 8 offers dietary standardisation for use in the nutrient-exercise intervention research among resistance-trained males. The protocol aimed to comply with dietary requirements, represent habitually consumed foods and fluids and meet participants’ food preferences. The provision of a standardised diet necessitated collaboration with an external food provider. Participants’ compliance to a standardised protocol was examined in the study. Chapter 9 is a general discussion of the research offered throughout this doctoral thesis. It examines achievement of aims and objectives, provides a synthesis of findings and demonstrates the practical application of the PEN method of dietary assessment. Finally, Chapter 10 summarises the current status of the PEN approach, challenges in the PEN implementation and further work required to improve its ease of use.

Together, these 10 chapters demonstrate that, if the scientific-evidence exists, the PEN approach offers advancements to dietary assessment by promoting time- and exercise-specific nutrients support, according to an individual’s aims. However, the use of the PEN approach will depend on further technological advancements of the PEN method and on the development of evidence-based dietary recommendations.
Chapter 2
Dietary Assessment Methods and Recommendations. Introduction to the Peri-Exercise Nutrition Approach

2.1. List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AI</td>
<td>Adequate Intake/s</td>
</tr>
<tr>
<td>CD</td>
<td>Competition day/s</td>
</tr>
<tr>
<td>DRI</td>
<td>Dietary Reference Intake/s</td>
</tr>
<tr>
<td>EAR</td>
<td>Estimated Average Requirement/s</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RD</td>
<td>Rest day/s</td>
</tr>
<tr>
<td>RDA</td>
<td>Recommended Dietary Allowance/s</td>
</tr>
<tr>
<td>SOP</td>
<td>Standard operating procedure</td>
</tr>
<tr>
<td>TD</td>
<td>Training day/s</td>
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2.2. Abstract

Dietary assessment, encompassing data collection and analysis, supports planning for appropriate dietary intakes. Among the general population and recreational to elite athletes, both retrospective and prospective methods of dietary assessment are commonly used in data collection. Technological advancements such as web-based assessment, voice recording, applications and image-based records or scales attached to software aim to increase the usability and accuracy of dietary assessment and reduce the burden for participants and practitioners. While some of the technological advancements are successfully applied in practice, such as 24-hour recall (Thompson et al. 2010), others, e.g. image-based records, need further development and testing (Stumbo 2013). Traditionally, dietary assessment involves assessing the adequacy of daily nutrient intakes against Dietary Reference Intakes (DRI) for the general population. Sport and exercise nutrition practice has evolved beyond generic daily prescriptions and provides evidence of increased daily macronutrient requirements and recommendations of nutrient intake per eating occasion (EO) for trained individuals and athletes. Moreover, the nutrient intake recommendations in sport and exercise nutrition promote the periodised, training- and intent-specific approach of nutrient provisions (Thomas et al. 2016). Additionally, evidence suggests that time-based nutrient intakes in proximity to exercise may support training adaptation and sports performance. Knowledge about the dietary practices of trained or athletic populations is informed by dietary assessment. In sport and exercise nutrition, dietary assessment is based on average daily, and per pre-defined EO energy and nutrient intakes. Often,
dietary assessment is differentiated on training days (TD), rest days (RD) and competition days (CD). However, dietary assessment tailored to an exercise session and an individual’s goals is limited.

To address these shortcomings, the peri-exercise nutrition (PEN) approach of dietary assessment was proposed. The PEN approach promotes time-specific, exercise- and intent-orientated dietary assessment and optimised energy and nutrient intakes [type, quality (source), quantity, time, frequency and distribution] in agreement with the scientific evidence. PEN data collection and analysis promote consistent quality of applied practice in sport and exercise nutrition. The PEN approach allows for effective monitoring of habitual dietary practices specific to single or multiple training sessions and competition events within a weekly microcycle in each particular phase of the season. The exploration of PEN practices in trained and athletic populations may inform the design of further research projects in sport and exercise nutrition to substantially increase the quality of dietary standardisations, as well as the outcome of nutrient-exercise interventions. PEN methods complement and advance the average daily and per EO nutrient intakes assessment among trained individuals.

2.3. Retrospective and Prospective Dietary Data Collection Methods
Current practices of dietary assessment used for athletic populations are divided into retrospective (24-hour recall, Food Frequency Questionnaire, diet history) and prospective (food intake record) data collection methods (Burke 2015). The 24-hour recall and Food Frequency Questionnaire are quantitative methods that rely on an athlete’s memory and commonly have been used from one to three times on non-consecutive occasions to assess the dietary intakes of an individual (Black 2001; Thompson and Subar 2013; Deakin 2015; Gillen et al. 2017). Another retrospective dietary assessment method is diet history, where diet-related information is collected based on recollections of the past seven days during one (60–90 minute) meeting (Black 2001). The prospective method of dietary assessment via food intake records allows for the weighed or estimated (pictures, household measures) collection of data at the time of intake.

2.3.1. Validity, Precision and Representativeness of Dietary Data Collection Methods
Selection of dietary assessment methods and duration of data record should reflect the desired outcomes among trained and athletic populations. When choosing data
collection methods, consideration should be given to data accuracy, reliability, representativeness of data and burden on participants and researchers (Burke 2015). Trained and athletic populations engage in exercise programmes that dictate nutrient intake requirements and variation in their intakes according to characteristics of an exercise session (Thomas et al. 2016). Hence, it is a common approach among researchers to examine the patterns and adequacy of nutrient intakes. Dietary intake records in comparison to other retrospective methods of assessment allow for investigation of daily nutrient intake patterns during the recording phase and do not rely on individual memory (Black 2001). A 3–7-day dietary record was suggested as an adequate method for assessment of energy and nutrient intakes among general and athletic populations (Basiotis et al. 1987; Magkos and Yannakoulia 2003). However, random, 1–4-day dietary records do not account for day-to-day variation in nutrient intakes within a weekly microcycle and were considered to be an inadequate representation of habitual intake among athletes (Burke 2015).

A 7-day record was shown to be the most precise method of energy and nutrient intake collection. It reduced variations in athletes’ energy and nutrient intakes by two to three-fold in comparison to the 1-day or 3-day record (Black 2001; Braakhuis et al. 2003; Capling et al. 2017). Additionally, a 7-day record decreases the error of data coding by research dietitians in comparison to 1-day or a 3-day record (Braakhuis et al. 2003). Lastly, a 7-day record allows for investigation of nutrient intake patterns within a weekly microcycle specific to training and competition demands (Burke 2015). Researchers recognised that 3–7-day food intake records are usually more burdensome than retrospective methods for individuals or research participants (Burke 2003; Deakin 2015). However, motivated athletes, who perceive dietary assessment to be a tool to improve their sports performance, may find that providing information to be less of a burden than for others (Burke 2015).

2.3.2. Weighed Versus Estimated Dietary Intake Records

Weighed and estimated records can be differentiated by the dietary intake record method. Weighing is identified as a demanding process for participants because all ingredients and leftovers have to be weighed before and after each EO, and then considered during analysis. However, weighed records have lower error margins than estimated food intake records (Black 2001). Weighed dietary recording is regarded as a gold standard in sport and exercise research disciplines (Black 2001; Burke 2015).
Table 1 characterizes strengths and weaknesses of 3-4-day and 7-day weighed and estimated food intake records. Furthermore, adaptation of technology to written methods of assessment offers opportunities to advance these methods to increase their accuracy, usability, reduce cost and time of data collection and processing (Khanna et al. 2010; Thompson et al. 2010; Stumbo 2013; Boushey et al. 2017).

Table 1 Characteristics and comparison between dietary intake records

<table>
<thead>
<tr>
<th>Dietary intake record</th>
<th>Estimated</th>
<th>Weighed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration</strong>&lt;sup&gt;2,3,5&lt;/sup&gt; of record</td>
<td>3–4 days</td>
<td>7 days</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Data usually collected for two weekdays and 1–2 days at the weekend.</td>
<td>Data collected during seven consecutive days.</td>
</tr>
<tr>
<td><strong>Methods of measuring food quantity</strong></td>
<td>Estimated using different techniques: pictures, food photograph atlas, household measures&lt;sup&gt;2,4&lt;/sup&gt;.</td>
<td>Scale, each item including beverages is weighed&lt;sup&gt;1,4&lt;/sup&gt;.</td>
</tr>
<tr>
<td><strong>Strengths</strong></td>
<td>Improves compliance to a dietary record in comparison to weighed record&lt;sup&gt;2,4&lt;/sup&gt;; Requires less time to record data than weighed food record; Adequately measures food intakes, if household measurements standardised between subjects&lt;sup&gt;2&lt;/sup&gt;.</td>
<td>Record is more accurate than an estimated record&lt;sup&gt;4,5&lt;/sup&gt;; May reduce inadequacy from limited knowledge of portion sizes or non-standardised portion sizes, between subjects&lt;sup&gt;2,5&lt;/sup&gt;.</td>
</tr>
<tr>
<td>Less of a burden than 7-day estimated food record&lt;sup&gt;5&lt;/sup&gt;; Requires less time to record.</td>
<td>A good illustration of the weekly pattern&lt;sup&gt;2&lt;/sup&gt;; A good characterisation of daily and training-related</td>
<td>Less of a burden than 7-day food record&lt;sup&gt;5&lt;/sup&gt;; Requires less time to record data than a 7-day diary.</td>
</tr>
</tbody>
</table>
## Dietary intake record

*Estimated nutrition intake pattern*².

### Weaknesses

- Less accurate than weighed food and fluid record¹, ², ³;
- Estimated record may simplify or improve habitual food and fluid intake¹, ², ⁴;
- Underestimation of actual energy consumed might be between 20–50%³, ⁴.

*Weighed nutrition intake pattern*².

- Time-consuming—all ingredients have to be weighed separately before (and after) each eating occasion¹, ⁴;
- The weighed record may simplify or improve habitual food and fluid intake by decreasing compliance to a dietary record¹, ², ⁴;
- Underestimation of actual energy consumed might be between 10–30%⁴.

<table>
<thead>
<tr>
<th>Non-standardised portion sizes might provide a higher error of estimation of consumed food quantities²;</th>
<th>Requires more time to record than a 3-4-day dietary record; Compliance might decrease as the duration of record increases⁴.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not enough choice of pictures with adequate food portion sizes²;</td>
<td>Requires more time to record than estimated records, because all ingredients have to be weighed separately¹, ⁴;</td>
</tr>
<tr>
<td>Poor characterisation of daily- and training-related nutrient intake patterns in comparison to seven days.</td>
<td>Poor characterisation of daily- and training-related nutrient intake patterns in comparison to seven days.</td>
</tr>
</tbody>
</table>

More demanding type of food record, in contrast to estimated or shorter duration record;

Involves a greater amount of time in contrast to other methods described in this table¹, ².

Compliance might decrease as the duration of record increases⁴, ⁵.
Both weighed and estimated dietary intake data collection methods require qualified dietician, nutritionist or educated staff to advise respondents on detailed data collection. After data collection, the data have to be entered into the software and be analysed by qualified professionals².

Note. ¹Black (2001); ²Burke (2015); ³Deakin (2015); ⁴Magkos and Yannakoulia (2003); ⁵Thompson et al. (2010).

2.4. Technological Advancements to Dietary Data Collection Methods

Software developments for 24-hour recall and Food Frequency Questionnaire records allow web-based access and computerisation of these methods. Technological advancements to 24-hour recall include a personal digital assistant, automated questions and standardised food portion sizes (Thompson et al. 2010). These advancements to the 24-hour recall allow it to be widely used in different environments (Thompson et al. 2010). For example, in terms of the Food Frequency Questionnaire, the computerised or scannable versions of the questionnaire have been used in epidemiological studies (Perez Rodrigo et al. 2015). The web-based Food Frequency Questionnaire with audio-recorded questions has been proposed for low literacy groups (Zoellner et al. 2005).

Technological adaptations that enhance food records include electronic, audio recording and photographing food intakes, using mobile applications and camera. For example, the electronic record allows recording nutrition information based on 15 categories and the 18 foods within each category (Thompson et al. 2010). A camera is another method for documenting food portions before and after consumption (Stumbo 2013). The camera used for an image-based record can be active when a subject takes a picture or passive when the body-worn device takes it for a subject (Boushey et al. 2017). Estimation of food intake that relies on photographic food options requires participants to be familiar with food portion sizes. Stumbo (2013) explained that the image-based dietary record software requires, for example, taking pictures of food consumed and providing additional details like food name and serving size. Other image-based examples include taking photos from different angles or measuring the volume of food.
It seems to be easier to assess the nutrient composition of meals if they consist of ingredients separated on a plate (e.g. rice with chicken and broccoli). The process of assessing multiple-ingredient, mixed dishes (e.g. chicken curry with rice) may be more challenging (Stumbo 2013). Once the volume of food is measured, it has to be accurately converted into weight (Partridge et al. 2018). Boushey et al. (2017) pointed out that a blurry food image or low light influences record quality. Alternatives to image-based assessment may require scanning food bar codes (Kretsch and Fong 1990) or weighing food. The Food Recording Electronic Device enables recording quantitative dietary data up to three weeks automatically via connection to software-based weighing scales. This device requires recognition of food products from provided food categories using a coder (Stockley et al. 1986).

More recently, industries along with the development of nutrition analysis software provide applications for food records. With electronic records, similar to written records, participants have to be informed about how to record quantities of consumed food, either using a scale, images or food portion sizes. Additionally, mobile applications require subjects’ familiarisation with appropriate food databases. Recording information via mobile application provides access to the practitioner for nutrition analysis and eliminates repetition of data coding in the nutrition analysis software (Wenhold 2018). Nevertheless, this method requires checking the data quality that subjects enter.

The mobile application suitable for food recording ought to provide a database that allows for choosing suitable food according to country, region and culture (Wenhold 2018). Participants of the study should be familiar with food coding, i.e. choosing representative food ingredients from databases, which in the “pen-and-paper” model is not required. Capling et al. (2017) concluded that there is a requirement for validation of advanced technological innovations in dietary assessment methods among athletic populations. Sharp and Allman-Farinelli (2014) proposed that validity testing in a variety of populations should be conducted to evaluate the efficacy of the new methodologies in research settings. Therefore, further study should confirm that the technologically advanced methods are superior to the written record, according to factors that include validity, repeatability, time of record, data quality check by practitioners and format of data required for analysis in practical and research settings. While it is anticipated that technological advancements should provide improved
functionality relative to the “pen-and-paper” approach when it comes to dietary assessments, the new methods should be carefully considered and selected according to population (patient or athlete) and setting (research or practice).

Development of new technologies may increase the usability and accuracy of dietary assessment and be less burdensome for participants and practitioners (Khanna et al. 2010; Stumbo 2013; Boushey et al. 2017). Additionally, computerised dietary assessment may give opportunities for self-assessment by participants that could assist professionals with a daily, dietary assessment approach. Computer programmes allow assessment choice: 24-hour recall, diet history, Food Frequency Questionnaire and food intake record, which can be engaged for one- to four- or more day periods (Probst and Tapsell 2005; Thompson et al. 2010). In trained and athletic populations, the advancements in dietary assessment methods integrate the dietary record with exercise logs, energy expenditure data, body composition and other relevant information (e.g. wake-up times and bedtimes) (Black 2001; Burke 2015; Kozior et al. 2019). Technological advancements to the dietary assessment methods presented in this section are viable opportunities for future replacement of current written methods.

2.4.1. Complementary Methods to Dietary Assessment

One of the complementary methods of dietary assessment is measurement of nutritional biomarker status. This method should be chosen carefully since nutritional biomarkers might reflect short- (e.g. urinary sodium) or long-term (e.g. toe-nail selenium) status of nutrient intakes. However, due to the poor relationship between biomarkers and dietary intake, and also biomarkers’ cost, they are not a preferred research approach (Thompson et al. 2010). Another method to supplement the dietary assessment method involves measurement of metabolite biomarkers from blood, saliva and urine samples. The assessment of metabolite biomarkers relates to nutrient, food intakes and dietary patterns. There are several individual foods and food groups that are of particular interest to researchers, including cocoa, coffee, wine, whole-grain bread, fish, meat, nuts, fruits and vegetables (Guasch-Ferré et al. 2018; Collins et al. 2019).

2.5. Assessment of Adequacy of Nutrient Intakes Using DRI Values

Dietary assessment is a component of direct nutritional assessment methods (mnemonic ABCD) (Figure 1) (Murphy and Poos 2002; British Association for
The aim of dietary assessment is to evaluate dietary intake of energy and nutrients in order to identify areas of change that will support individual health (Institute of Medicine 2000b). The average daily nutrient intake values recorded over multiple days are compared to DRI, dependent on jurisdiction and population. The prevalence of adequacy in dietary intakes for healthy individuals and groups of individuals should be compared to the Estimated Average Requirements (EAR) or the Adequate Intakes (AI) if the EAR are not established (Institute of Medicine 2000b). The Recommended Dietary Allowances (RDA) can be used to assess individuals’ intakes (Institute of Medicine 2000a). However, to assess the adequacy of nutrient intakes using the RDA, long term data must be collected. Moreover, the reported intake to be classified as adequate should be at or above the RDA values (Murphy and Poos 2002). According to Murphy and Poos (2002), when assessing the adequate nutrient intakes based on short-term assessment, the reported values should be above the RDA for an individual. Basiotis et al. (1987) discussed the number of days that should be recorded to assess usual intakes of a particular nutrient for groups and individuals. However, it should be highlighted that, from “dietary data alone it is only possible to estimate the likelihood of nutrient adequacy or inadequacy” (Institute of Medicine 2005b).

The DRI values, which are derived from a general population, do not differ for trained and athletic populations (Institute of Medicine 2003). Researchers considered amending DRI values for athletes for most nutrients, but particularly for protein, B vitamins, and vitamins C and E. However, as a consequence of insufficient scientific evidence to support these changes the DRI were not altered for the athletic population, except for iron (Institute of Medicine 2003). The daily requirements for iron for athletes engaged in intensive exercise may be 30–70% higher than for healthy individuals of average physical activity (Institute of Medicine 2003). Further development of energy and macronutrient dietary recommendations have been proposed in joint position statements for athletic populations (Rodrigue et al. 2009; Thomas et al. 2016).
Figure 1 Traditional direct nutritional assessment using the mnemonic ABCD (anthropometry, biochemistry, clinical data, and dietary assessment).

Note. ¹Using the food pyramid and the basic food groups determines the number of servings from each group and compares it with minimum requirements; ²Amount of energy and specific nutrients in food consumed can be calculated using food composition and then compared with the recommended daily intake.

2.6. Assessment of Adequacy of Nutrient Intakes for Athletes Using Dietary Guidelines in Sport and Exercise Nutrition

The joint position statement of the Academy of Nutrition and Dietetics, Dietitians of Canada and the American College of Sports Nutrition (Thomas et al. 2016) presents guidelines for nutrient intakes and hydration strategies to promote athlete health, optimal physiological functions, recovery and performance. The guidelines offer daily and per EO macronutrient recommendations, relative to an individual’s body mass. Furthermore, the nutrient requirements are discussed in pre-, during- and post-exercise scenarios while addressing a variety of athletes’ goals (Thomas et al. 2016). Among athletic populations, the micronutrients of particular concern are iron, calcium, vitamin D and antioxidants (Thomas et al. 2016).

In addition to daily, per EO or in proximity to exercise session nutrient intake recommendations, researchers advocate for periodised nutrient support, which represents a long-term, structured, performance-orientated approach. Periodised nutrient support varies throughout a year within macrocycles (months to years),
mesocycles (weeks to months), and microcycles (within days to weeks) (Jeukendrup 2017; Stellingwerff et al. 2019). In sport and exercise nutrition, periodised nutrition, interchangeably called training nutrition, aims to support athletic performance through nutrition or a combination of nutrition and exercise, based on a progressive and purposeful routine. Therefore, periodised nutrition offers practical solutions in line with the training goals and nutrient requirements of an individual athlete rather than proposing a one-size-fits-all approach (Stellingwerff et al. 2007; Stellingwerff et al. 2011; Jeukendrup 2017; Burke et al. 2018; Stellingwerff et al. 2019).

Dietary and exercise strategies are superior to exercise-induced training adaptation and sports performance alone (Jeukendrup 2017). The adequate nutrient intakes in a nutrient-exercise approach consider the type, quality, quantity, distribution and time of nutrient intakes (Jeukendrup 2017; Kerksick et al. 2017). The role of a sports dietitian is to assess the adequacy of dietary practices for energy, nutrient and fluid intakes, specific to exercise and during rest, taper and travel days (Thomas et al. 2016). Hence, a sports dietitian may require more detailed information about habitual nutrient intakes to assess the adequacy of dietary practices beyond average daily assessment. Despite growing scientific evidence that offers time-sensitive, exercise-specific recommendations for macronutrient intakes, it is still unknown if athletes meet these requirements to optimise sports performance within their daily dietary intake patterns (Heikura et al. 2017).

### 2.7. Examples of Dietary Assessment Methods Among Athletes

Commonly, the process of dietary assessment in general and athletic populations are similar. The same methods and software are used firstly to collect and secondly to code dietary data on a daily basis. However, there is a difference found in the analysis of daily nutrient intakes. The nutrient intakes of the general population are often examined on week and weekend days (McCarthy 2014), while athletes’ nutrient intakes are usually assessed on training, rest or competition days (Erdman et al. 2013; Bettonviel et al. 2016; Anderson et al. 2017a; Brinkmans et al. 2019; Carr et al. 2019). Differences in the dietary analysis patterns between populations may be determined by work, education and other activities of daily living (McCarthy 2014). Additionally, in populations engaged in exercise programmes, the patterns of nutrient intakes may be altered by sports discipline requirements, e.g. training programme, individuals’ goals or competition schedule (Magkos and Yannakoulia 2003). Increasingly, research
studies examine macronutrient intakes per EO among athletes, in addition to daily assessment (Burke et al. 2003; Erdman et al. 2013; MacKenzie et al. 2015; Gillen et al. 2017; Brinkmans et al. 2019; Carr et al. 2019). There is also limited but growing evidence of research that has investigated nutrient intakes in proximity to a specific training session (Burke et al. 2003; MacKenzie et al. 2015) or training and competition events (Anderson et al. 2017a; Anderson et al. 2017b; Carr et al. 2019). Table 2 presents examples of research studies that used quantitative methodologies to assess nutrient intakes among athletes, in addition to average daily assessment of the recorded phase.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Sports discipline</th>
<th>Participants</th>
<th>Type of day</th>
<th>Type of exercise</th>
<th>Method of dietary data collection, software used</th>
<th>Method of data classification</th>
<th>Method of dietary analysis</th>
<th>Reference values for assessed nutrients</th>
<th>Overview of results (M ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anderson et al. (2017a)</strong></td>
<td>Soccer</td>
<td>6 male professional soccer players, English Premier League, first-team squad, represented countries at national level.</td>
<td>5 Training days, 2 Match days.</td>
<td>Not specified</td>
<td>24-hour food recall followed by a 7-day dietary intake record (food, drinks), with remote food photographic method. Software: Nutritics Ltd., Ireland</td>
<td><strong>Meals</strong> classification based on time intervals and type of consumption. <strong>Training days:</strong> Breakfast-main meal 6:00–9:30 <strong>Morning snack</strong>-foods consumed between the breakfast main meal and lunch. <strong>Lunch</strong>-main meal 11:30–13:30 <strong>Afternoon snack</strong>-foods consumed between lunch and dinner. <strong>Dinner</strong>-main meal 17:00–20:00 <strong>Evening snack</strong>-foods consumed after</td>
<td>Energy (kcal·meal⁻¹, kcal·kg⁻¹ LBM meal⁻¹) and macronutrient (g·meal⁻¹, g·kg⁻¹ BM meal⁻¹) intakes and their distribution per meal.</td>
<td>Carbohydrate Pre-match meal: e.g. 2–3 g·kg⁻¹ BM meal⁻¹, During match: 60 g·h⁻¹ meal⁻¹ Post-match: 1.2 g·kg⁻¹ BM for several hours (Whe et al. 2005; Foskett et al. 2008). Other carbohydrate guidelines to support physical (Burke et al. 2011), technical (Ali and Williams 2009) and cognitive (Welsh et al. 2002) performance. Protein: 40 g·kg⁻¹ BM meal⁻¹</td>
<td>Mean values are given based on available figures in the paper. Carbohydrate intake per meal on TD (g·kg⁻¹ BM meal⁻¹): All type of meals except for dinner and evening snack: &gt;0.5–&lt;1 Dinner: &gt;1.5 Evening snack &lt;0.5 Carbohydrate intake per meal on match days (g·kg⁻¹ BM meal⁻¹): Match time 16:15 Pre-match meal: &lt;1.5 Pre-match snack: ~0.7 During match: ~0.5 Post-match: &lt;1.5 Post-match recovery meal: ~1.8 Match time 20:05 Pre-match meal: &lt;1.5 Pre-match snack:</td>
</tr>
<tr>
<td>Reference</td>
<td>Sports discipline</td>
<td>Participants</td>
<td>Type of day</td>
<td>Type of exercise</td>
<td>Method of dietary data collection, software used</td>
<td>Method of data classification</td>
<td>Method of dietary analysis</td>
<td>Reference values for assessed nutrients</td>
<td>Overview of results $(M \pm SD)$</td>
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<td></td>
<td></td>
<td>dinner and before sleep.</td>
<td></td>
<td></td>
<td>(Res et al. 2012; Macnaughton et al. 2016)</td>
<td>$&lt; 0.5$ Post-match and post-match recovery meal $&lt; 1$ Detailed information about energy and macronutrient intakes per meal can be found in the journal article by these authors.</td>
</tr>
<tr>
<td>Reference</td>
<td>Sports discipline</td>
<td>Participants</td>
<td>Type of day</td>
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<td>Method of dietary data collection, software used</td>
<td>Method of data classification</td>
<td>Method of dietary analysis</td>
<td>Reference values for assessed nutrients</td>
<td>Overview of results $(M \pm SD)$</td>
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<td>Anderson et al. (2017b)</td>
<td>Soccer</td>
<td>6 male professional soccer players, English Premier League, first-team squad, represented countries at national level.</td>
<td>5 Training days, 2 Match days.</td>
<td>Team (duration, total distance, running distance, high-speed running distance, sprinting distance).</td>
<td>24-hour recall followed by a 7-day dietary intake record (foods, drinks) with remote food photographic method; 7 days doubly labelled water technique. Software: Nutritics Ltd., Ireland</td>
<td>Daily energy (kcal·d⁻¹, kcal·kg⁻¹LBM·d⁻¹) and macronutrient (g·d⁻¹, g·kg⁻¹BM·d⁻¹) intakes on training and match days. Carbohydrate intake (g·h⁻¹) and source during training and match sessions.</td>
<td>Carbohydrate: 30–60 g·h⁻¹ optimise physical (Burke et al. 2011) technical (Ali and Williams 2009) and cognitive (Welsh et al. 2002) performance.</td>
<td>Daily energy intake (kcal·kg⁻¹LBM·d⁻¹): CD v TD 61.1 ± 11.4 v 45.2 ± 9.3, $P &lt; .05$, $d = 1.7$ Daily carbohydrate intake (g·kg⁻¹BM·d⁻¹): CD v TD: 6.4 ± 2.2 v 4.2 ± 1.4, $P &lt; .05$, $d = 4.2$ Carbohydrate intake during training and games (g·h⁻¹): TD v CD: 3.1 ± 4.4 v 32.3 ± 21.9, $P &lt; .05$, $d = 6.6$.</td>
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<td>Brinkmans et al. (2019)</td>
<td>Soccer</td>
<td>45 male, professional soccer</td>
<td>1 Rest day (no exercise), Exercise during training</td>
<td>Three, 24-hour recalls recorded</td>
<td><strong>Main meals</strong> defined as breakfast, Daily energy (reported in different units)</td>
<td>Protein: 20–25 g main meal⁻¹, 30–40 g before</td>
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<td>Daily energy intake (MJ·d⁻¹): $13.8 \pm 1.5$ TD v CD: $11.1 \pm 3.4$</td>
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<td>players, Dutch Premier League (Eredivisie).</td>
<td>1 training day, 1 Match day.</td>
<td>day-field training either 3 days before or 2 days after a match, Exercise during match day-considered if a player played for at least 60 minutes (the information about time on the field, maximum speed, distance, speed zones was given).</td>
<td>using standardised portion sizes and measures, 14 days doubly labelled water technique. Software: Compl-eat™ (Wageningen University, Division of Human Nutrition)</td>
<td>lunch, and dinner.</td>
<td>and macronutrient, fibre (g·d⁻¹, g·kg⁻¹ BM·d⁻¹, % of TEI) and water (L·d⁻¹) intakes in all players and in playing position groups. Protein intake distribution (proportion of total players who did not meet 20g of protein per main meal or snack) and source (proportion of total protein intake, %).</td>
<td>sleep (Phillips and Van Loon 2011; Trommelen and van Loon 2016). Protein: 1.2–1.7 g·kg⁻¹ BM·day⁻¹ (Tipton and Wolfe 2004; 'Nutrition for football: the FIFA/F-MARC Consensus Conference' 2006; Boisseau et al. 2007). Carbohydrate: 5–7 g·kg⁻¹ BM·day⁻¹-moderate training days, 7–12 g·kg⁻¹ BM·day⁻¹-heavy training days or match preparation ('Nutrition for football: the FIFA/F-MARC Consensus Conference').</td>
<td>v $13.1 \pm 4.1$, $P = .026$ CD v RD: $13.1 \pm 4.1$ v $10.5 \pm 3.1$, $P = .007$ Daily protein intake (g·kg⁻¹ BM·d⁻¹): 1.7 ± 0.5 TD v CD: $1.7 \pm 0.6$ v $1.8 \pm 0.6, P &lt; .05$ CD v RD: $1.8 \pm 0.6$ v $1.5 \pm 0.5, P &lt; .05$ Daily carbohydrate intake (g·kg⁻¹ BM·d⁻¹): 4.0 ± 1.2 TD v CD: $3.9 \pm 1.5$ v $5.1 \pm 1.7, P = .005$ CD v RD: $5.1 \pm 1.7$ v $3.7 \pm 1.4, P = .001$ Daily fat intake (g·kg⁻¹ BM·d⁻¹): 1.2 ± 0.5 RD: $1.2 \pm 0.5$ TD: $1.2 \pm 0.6$ CD: $1.33 \pm 0.6$ Non-statistically significant difference between all conditions for fat intake. Protein source (% of total protein intake) Plant: 28%</td>
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<td>Reference</td>
<td>Sports discipline</td>
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<td>Burke et al. (2003)</td>
<td>Different sport disciplines.</td>
<td>167 Australian Olympic athletes, (87 male, 80 female athletes, including 41 endurance sports, 31 team sports, 67 sprint- or skill-based sports 28 weight-conscious sports athletes).</td>
<td>Not specified (but included training days).</td>
<td>Not specified</td>
<td>Eating occasion-food or energy-containing drinks consumed within 30 minutes. EO classification based on time intervals.</td>
<td>Breakfast: 5:00–9:59 Morning tea: 10:00–11:59 Lunch: 12:00–14:59 Afternoon tea: 15:00–17:59 Dinner: 18:00–20:59 Evening snack: 21:00–04:59 Training: all energy-containing foods and fluids consumed</td>
<td>Daily energy (MJ·d⁻¹, MJ·kg⁻¹ BM·d⁻¹) and macronutrient intakes (g·d⁻¹, g·kg⁻¹ BM·d⁻¹, % of TEI·d⁻¹) in all athletes, sex and sport groups. Proportion (% of TEI) of energy intake of macronutrients per meal and snack in all athletes, sex and sport groups.</td>
<td>Carbohydrate within 1-hour post-training “Fully achieved”: &gt; 0.8 g·kg⁻¹ BM, “Some attempt at recovery”: 0.4–0.8 g·kg⁻¹ BM, “No recovery achieved”: &lt; 0.4 g·kg⁻¹ BM (Burke et al. 2001). Nutrient intakes were also compared to Convertino et al. (1996). American College of Sports Medicine; American Dietetic Association; Dietitians of Canada et al. (2000).</td>
<td>Carbohydrate (g·kg⁻¹ BM·d⁻¹): 5.2 ± 1.8 Daily carbohydrate intake (g·kg⁻¹ BM·d⁻¹): 0.4–0.8 g·kg⁻¹ BM</td>
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<td>Carr et al. (2019)</td>
<td>Cross-country skiing</td>
<td>31 national cross-country skiers (18 male, 13 female athletes)</td>
<td>1 training day, 1 simulated competition day, 2-day weighed food record (meals were provided to participants by a chef), Low Energy Availability in Females Questionnaire. Software: Dietist XP</td>
<td>Meals classified as (no further definition was given): Breakfast Lunch Dinner Snacks Pre-Exercise consumed within 1–4 hours before exercise</td>
<td>Daily energy intake (kcal·d⁻¹, kcal·kg⁻¹ BM·d⁻¹) and macronutrient (g·kg⁻¹ BM·d⁻¹) and fluid mL·kg⁻¹ BM·d⁻¹) intakes in sex groups, comparison training v competition days.</td>
<td>Requirements of daily macronutrient and pre-, during and post-exercise carbohydrate and fluid and post-exercise protein intakes were compared to guidelines from Phillips and Van Loon</td>
<td>Requirements of daily macronutrient and pre-, during and post-exercise carbohydrate and fluids, or carbohydrate without fluids was consumed or no intake was reported (%). The proportion of total training sessions undertaken after which either adequate, inadequate or no carbohydrate was consumed (%).</td>
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<td>skiing in the morning, classical/skate skiing in the afternoon (duration, heart rate were given).</td>
<td>Version 2016, Diet and Nutrition Data AB, Bromma, Sweden)</td>
<td>During exercise</td>
<td>Post-exercise-consumed within 1–4 hours after exercise.</td>
<td>Carbohydrate (g·kg⁻¹ BM) and fluid (mL·kg⁻¹ BM) intakes 1–4 hours pre- and during, 1–4 hours post-exercise, and protein intake (g·kg⁻¹ BM) 1–4 hours post-exercise around AM and PM exercise sessions daily on both days for males and females. The proportion of participants who met recommendations (%) pre-, during and post-exercise. Carbohydrate (g·kg⁻¹ BM) and protein intake (g·kg⁻¹ BM) for males and females.</td>
<td>(2011); Phillips (2012); Thomas et al. (2016). The detailed information can be found in Table 5 in Carr et al. (2019).</td>
<td>v 3.3 ± 0.6, P = .065 Daily protein intake for females (g·kg⁻¹ BM·d⁻¹): TD v CD: 3.0 ± 0.6 v 2.8 ± 0.4, P = .197 Daily carbohydrate intake for males (g·kg⁻¹ BM·d⁻¹): TD v CD: 8.2 ± 2.3 v 8.9 ± 2.3, P = .002 Daily carbohydrate intake for females (g·kg⁻¹ BM·d⁻¹): TD v CD: 7.0 ± 1.5 v 8.5 ± 1.7, P = .003 Daily fat intake for males (% of TEI·d⁻¹): TD v CD: 32 ± 4 v 35 ± 4, P = .436 Daily fat intake for females (% of TEI·d⁻¹): TD v CD: 28 ± 5 v 32 ± 4, P = .605 Daily fluid intake for males (mL·kg⁻¹ BM·d⁻¹): TD v CD: 125.8 ± 14.5 v 64.1 ± 16.3, P = .001 Daily fluid intake for males (mL·kg⁻¹)</td>
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<td>Erdman et al. (2013)</td>
<td>Different sport disciplines.</td>
<td>325 Canadian high-performance athletes (114 male, 201 female athletes) representing 41 different sport disciplines (26 summer and 15 winter sport disciplines).</td>
<td>At least 2 training days of a 3-day record.</td>
<td>Not specified</td>
<td>3-day dietary intake record (foods, fluids, dietary supplements) Software: Food Smart nutrition software (Version 2, Envision Health Networks Inc.).</td>
<td>Daily energy and macronutrient intakes per EO (time-based meals and snacks, no further definition for EO was given). Six EO were identified as: Breakfast a.m. snack Lunch p.m. snack Dinner Evening snack.</td>
<td>Daily energy (kcal·d⁻¹) and macronutrient intakes (g·d⁻¹, g·kg⁻¹·BM·d⁻¹, % of TEI·d⁻¹) comparison by sex, and age groups, comparison training v rest days, meal v snack. Energy (kcal·EO⁻¹) and macronutrient intakes (g·EO⁻¹) per EO in sex groups. Breakdown of percentage of TEI from six categories for Daily protein and carbohydrate intake according to the Rodriguez et al. (2009).</td>
<td>Energy intake (kcal·d⁻¹): Total daily 2636 ± 863 TD v RD: 2781 ± 1045 v 2572 ± 1,042, P = .002 Protein intake (g·kg⁻¹·BM·d⁻¹): Total daily: 1.9 ± 0.6 TD v RD: 2.0 ± 0.7 v 1.8 ± 0.6, P = .002 Carbohydrate intake (g·kg⁻¹·BM·d⁻¹): Total daily: 5.4 ± 1.8 TD v RD: 5.6 ± 1.9 v 5.0 ± 2.1, P = .001 Fat intake (g·kg⁻¹·BM·d⁻¹): Total daily: 1.2 ± 0.5</td>
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Energy intake (kcal·d⁻¹): Total daily 2636 ± 863 TD v CD: 70.6 ± 10.8 v 2.2 ± 16.6, P = .083 Refer to paper for further detailed results about pre-, during- and post-exercise session nutrient intakes.
<table>
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<tr>
<th>Reference</th>
<th>Sports discipline</th>
<th>Participants</th>
<th>Type of day</th>
<th>Type of exercise</th>
<th>Method of dietary data collection, software used</th>
<th>Method of data classification</th>
<th>Method of dietary analysis</th>
<th>Reference values for assessed nutrients</th>
<th>Overview of results (M ± SD)</th>
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<td>Gillen et al. (2017)</td>
<td>Different sport disciplines.</td>
<td>553 well-trained athletes (327 male, 226 female athletes) representing endurance, team and strength sport disciplines.</td>
<td>2 weekdays, 1 weekend day.</td>
<td>Not specified but duration (min) of training was recorded.</td>
<td>Three, 24-hour web-based recalls and a dietary supplement questionnaire. Software: Compl-eat™ ( Wageningen University, Division of Human Nutrition), Dutch Food Composition Database (Stichting NEVO, 2010)</td>
<td>Protein intake was categorised into six categories (no definition was given): Breakfast snack Morning snack Lunch Afternoon snack Dinner Evening snack.</td>
<td>Daily energy (MJ·d⁻¹) and protein intakes (g·d⁻¹, g·kg⁻¹·BM·d⁻¹, % of TEI). Protein intake distribution throughout a day according to six categories. Daily and per-category source of protein intake (g·category⁻¹, % of total protein intake·category⁻¹).</td>
<td>Reference values for assessed nutrients</td>
<td>Daily energy intake (MJ·d⁻¹): Males: 11.5 ± 3.2 Females: 9.0 ± 2.4 Total daily protein intake (g·kg⁻¹·BM·d⁻¹): Males: 1.5 ± 0.4 Females: 1.4 ± 0.4 Daily protein source (%·d⁻¹ of total protein intake): Plant Males: 44 ± 11 Females: 43 ± 13 Animal Males: 56 ± 11 Females: 57 ± 13.</td>
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<td>Reference</td>
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<td>MacKenzie et al. (2015)</td>
<td>Rugby</td>
<td>25 male, developing elite rugby union athletes.</td>
<td>6 training days.</td>
<td>Minimum 3 resistance exercise sessions, and regular skills and fitness sessions.</td>
<td>7-day estimated dietary intake record using standardised household measures (foods, fluids, dietary supplements). Software: Foodworks V6.0.2562</td>
<td>Eating occasion-energy-containing food or fluid consumed &gt; 30 minutes apart. <strong>Protein distribution score (20 g)</strong>-the number of EO per day containing over 20 g of protein averaged across the week. <strong>Post resistance exercise protein</strong>-the number of EO immediately after resistance exercise containing over 20 g of protein averaged across the week.</td>
<td>Daily energy (kcal, kJ·d⁻¹, kJ·kg⁻¹·BM·d⁻¹) and macronutrient intakes (g·d⁻¹, g·kg⁻¹·BM·d⁻¹, % of TEI). Number of EO. Protein intake according to defined scores.</td>
<td>Protein: ~0.25–0.3 g·kg⁻¹·EO⁻¹ evenly spaced on ~4 occasions (Churchward-Venne et al. 2012b; Res et al. 2012; Areta et al. 2013). Carbohydrate: 5–7 g·kg⁻¹·BM·d⁻¹ (Bradley et al. 2015).</td>
<td>Total daily energy intake (kcal·d⁻¹): 3250 ± 869 Total daily protein intake (g·kg⁻¹·BM·d⁻¹): 2.2 ± 0.7 Total daily carbohydrate intake (g·kg⁻¹·BM·d⁻¹): 3.6 ± 1.3 Total daily fat intake (g·kg⁻¹·BM·d⁻¹): 1.1 ± 0.5 Number of EO: 5.6 ± 1.0 Protein distribution score (20 g): 3.8 ± 0.9 Post resistance exercise protein: 0.5 ± 0.2.</td>
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<td>Naughton et al. (2016)</td>
<td>Soccer</td>
<td>59 male elite youth soccer players from the English No competitive matches</td>
<td>Soccer training and non-soccer</td>
<td>7-day dietary intake record using standardised <strong>Meals</strong> were classified based on time of consumption:</td>
<td>Daily energy (kcal·d⁻¹, kcal·kg⁻¹·BM·d⁻¹) and daily protein intake (g·kg⁻¹·BM·d⁻¹) (players aged U13/14s: 43.1 ± 10.3).</td>
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<td>Protein: 1.4–1.6 g·kg⁻¹·BM·d⁻¹ (players aged U13/14s: 43.1 ± 10.3).</td>
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<td>Daily energy intake (kcal·kg⁻¹·BM·d⁻¹): 3250 ± 869 Total daily protein intake (g·kg⁻¹·BM·d⁻¹): 2.2 ± 0.7 Total daily carbohydrate intake (g·kg⁻¹·BM·d⁻¹): 3.6 ± 1.3 Total daily fat intake (g·kg⁻¹·BM·d⁻¹): 1.1 ± 0.5 Number of EO: 5.6 ± 1.0 Protein distribution score (20 g): 3.8 ± 0.9 Post resistance exercise protein: 0.5 ± 0.2.</td>
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<td>Premier League</td>
<td>took place over 7 days</td>
<td>training (min.)</td>
<td>household measures or weight, number of items and volume was provided from food packages (foods, fluids, dietary supplements).</td>
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<td><strong>Breakfast</strong>-main meal between 6:00–9:30</td>
<td><strong>Lunch</strong>-main meal 11:30–13:30</td>
<td><strong>Dinner</strong>-main meal 17:00–20:00</td>
<td><strong>Snacks</strong>-foods consumed between main meals.</td>
<td>macronutrient intakes (g d$^{-1}$, g·kg$^{-1}$ BM·d$^{-1}$) in age groups (U13/14s, U15/16s, U18s). Protein and carbohydrate intake per meal (g·meal$^{-1}$, g·kg$^{-1}$ BM·meal$^{-1}$) in age groups (U13/14s, U15/16s, U18s).</td>
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<td>Note. Results present daily energy and nutrient intakes, including frequency of EO consumed, in some cases called “meals”. Energy and macronutrient values per each identified EO were not provided in this table. When authors reported nutrient intakes in proximity to training, the information was included in the table, except for Carr et al. (2019), due to detailed information provided. BM–Body mass; CD–Competition day/s (including match days); EO–Eating occasion/s; LBM–Lean body mass; M–Mean; TD–Training day/s; TEI–Total energy intake; RD–Rest day/s; SD–Standard deviation.</td>
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2.8. Dietary Intake Analysis per Pre-Defined EO in Sport and Exercise Nutrition

An EO is one of the descriptors used by researchers to classify food and fluid intakes recorded during dietary data collection. Other terms to describe an EO include main meals, meals and snacks. Burke et al. (2003) defined an EO as “food or energy-containing drinks” consumed within 30-minute intervals. Food and energy containing drinks recorded during data collection were classified into one of five, pre-defined EO according to the time of its consumption (e.g. food consumed between 05:00–09:59 were classified as breakfast, 12:00–14:59 as lunch, and 18:00–20:59 as dinner). Other researchers adopted the EO term, often proposing their own classification of EO (Erdman et al. 2013; Gillen et al. 2017). The assessment of nutrient quantity per pre-defined EO and EO frequency became a common assessment of daily dietary intake in athletic populations, to inform daily nutrient intake patterns. Furthermore, in assessing intake patterns per EO, special attention was given to the quantity of protein intake per EO and frequency of EO (MacKenzie et al. 2015; Gillen et al. 2017), and quantity of carbohydrate intake (Burke et al. 2003; Anderson et al. 2017a; Anderson et al. 2017b) in athletic populations. According to the previous research studies that offered dietary assessment per EO (see Table 2), the summary of the strengths and weaknesses of this assessment is presented in Table 3 (Burke et al. 2003; Erdman et al. 2013; MacKenzie et al. 2015; Naughton et al. 2016; Anderson et al. 2017a; Anderson et al. 2017b; Gillen et al. 2017; Brinkmans et al. 2019).

Table 3 Strengths and weaknesses of dietary assessment per time-grouped EO

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
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<td>Standardises data coding within a research group.</td>
<td>There are not standardised definitions among research groups to compare data (e.g. different timeframes of grouped EO, lack of information if the published assessment includes dietary supplement and alcohol intakes).</td>
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<td>Allows for comparing time-grouped nutrient intakes between populations during a different part of a day, if the same terminology were used for breakfast, lunch etc.</td>
<td>Does not allow for comparison of results if different terminology is used between studies.</td>
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<td>Advances current understanding of dietary intake patterns within a day (quantity, nutrient distribution throughout a day based on...</td>
<td>Does not provide information about nutrient intakes distribution throughout a day based on...</td>
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<td>Strengths</td>
<td>Weaknesses</td>
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<td>source, frequency, part of a day e.g. morning, afternoon.</td>
<td>real-time of nutrient intakes. May not provide a true frequency of EO if the fixed number of EO is proposed and only one EO can be classified within a category.</td>
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<td>Reveals discrepancies of nutrient intakes within different parts of a day (e.g. breakfast, afternoon snack);</td>
<td>Hides discrepancies of nutrient intakes at a specific time of nutrient intakes (e.g. 7:30 am, 6:30 pm);</td>
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<td>Reflects the part of a day within which EO was consumed (e.g. breakfast between 05:00-09:59).</td>
<td>Does not reflect time of nutrient intakes in proximity to an exercise session among trained and athletic populations.</td>
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*Note. EO–Eating occasion.*

### 2.9. Dietary Intake Analysis per EO as Part of Traditional Dietary Assessment Methods Among Trained Individuals

Daily dietary assessment that includes the type of day (i.e. training, rest or competition day) and dietary assessment per EO, were considered to be traditional dietary assessments among trained individuals, for this thesis. Daily and per EO dietary analyses for resistance-trained and endurance-trained individuals are presented in later chapters of this thesis (Chapter 5 and Chapter 7, respectively). Before dietary assessment, the general EO term was defined in line with previous research (Burke et al. 2003) and further customized according to the time and energy intake of a single EO. A single EO was defined as intake of energy-containing (> 0 kcal) food, fluids, alcoholic beverages and dietary supplements. A 30-minute time-band for a single eating occasion was adopted from Burke et al. (2003). The detailed time-grouped descriptors for EO and relevant intakes of fluids and dietary supplements that were energy-free were coded into the software as identified in Table 4. Moreover, the nutrition analysis software (Nutritics Ltd., Ireland) accommodated customisation for the addition of data entry fields to conduct dietary intake analysis for trained individuals. The software customisation included the addition of date, time, type of EO, place of EO preparation (i.e. home, school, work, friend's house, family house, pub, restaurant, hotel, shop, café, catering, take away and fast food outlet) and type of day (i.e. training, rest and competition days) data entry fields.
Table 4 Terminology of EO and other relevant intakes

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eating occasion (EO)</td>
<td>An intake of energy-containing (&gt; 0 kcal) food, fluids, including alcoholic beverages, and dietary supplements within a discrete, 30-minute timeframe. 0 kcal fluids, 0 kcal dietary supplements are classified as part of an EO if they are consumed at the same time as energy-containing foods, and/or fluids.</td>
</tr>
<tr>
<td>Type of EO</td>
<td>Breakfast, lunch, dinner, snack, pre-sleep snack, alcoholic beverage.</td>
</tr>
<tr>
<td>Main EO</td>
<td>An EO with the highest energy intake consumed 6:00–11:00 is classified as breakfast, 11:01–15:00 lunch, 15:01–22:00 dinner (excluding alcohol consumed exclusively). Alcohol is classified as part of this category when it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.</td>
</tr>
<tr>
<td>Snack</td>
<td>Each EO consumed between the main EO; intake of energy-containing (&gt; 0 kcal) food, fluids and dietary supplements. Alcohol is classified as part of this category if it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.</td>
</tr>
<tr>
<td>Pre-sleep snack</td>
<td>A snack consumed 0–1 hour before bedtime.</td>
</tr>
<tr>
<td>Alcoholic beverage</td>
<td>A single EO that contains alcohol only. An alcoholic beverage consumed with other fluids (0 kcal) is classified under this category. Alcohol consumed with energy-containing food, fluids and/or dietary supplements is part of other EO categories that include main EO or snacks.</td>
</tr>
<tr>
<td>0 kcal fluid^1</td>
<td>Water or energy-free fluids consumed in isolation (not with an energy-containing item) that do not provide energy (0 kcal). Fluid intake (0 kcal) with other energy-containing food, fluids and/or dietary supplements is part of other EO categories, such as main EO, snack or alcoholic beverage.</td>
</tr>
<tr>
<td>0 kcal dietary supplement ^1</td>
<td>A dietary supplement is defined as “a food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of</td>
</tr>
<tr>
<td>Descriptor</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>achieving a specific health and/or performance benefit” (Maughan et al. 2018). Only dietary supplements (0 kcal) consumed alone or with 0 kcal fluids should be included in this category. If a consumed supplement contains &gt; 0 kcal or is consumed alongside energy-containing food and/or fluids, it should be classified as under one of the EO categories. Examples of products that are classified as EO and not supplements due to their contribution to energy include fish oils, spirulina powder, lecithin powder, acai powder, protein powder etc.</td>
</tr>
</tbody>
</table>

Note. 10 kcal fluids and 0 kcal dietary supplements are coded into software under stand-alone descriptors but are not defined as EO. According to the definition, they do not contribute to the total energy intake. 0 kcal fluids and 0 kcal dietary supplements do not contribute to the analysis of EO frequency.

2.10. Peri-Exercise Nutrition—Advancement to Dietary Assessment Methods

Daily and per EO dietary assessment methods have limited application in sport and exercise nutrition since they fail to address

- nutrient periodisation—the actual time and dietary requirements of single EO and particularly those EO—in significant proximity to training or competitive events (Jeukendrup 2017; Burke and Hawley 2018); and

- specific daily dietary demands of sport disciplines dependent on the exercise periodisation (i.e. day-to-day variability) including exercise type, volume, intensity and intent (Table 6).

These are notable omissions in the pursuit of personalised nutrition (dietary and phenotype levels) (Gibney and Walsh 2013) according to the requirements of athletes’ particular exercise sessions and individual goals, which might compromise outcomes, for example exercise adaptation, performance or body composition (Jeukendrup 2017; Kerksick et al. 2017). To address these shortcomings, the peri-exercise nutrition (PEN) methodology was proposed.
The PEN approach is a novel advancement to traditional dietary assessment that includes data collection, analysis and prescription (i.e. recommended energy and nutrient intakes informed by scientific evidence) among trained individuals (Figure 2). The PEN approach promotes time-specific, exercise- and intent-orientated dietary assessment and optimised energy and nutrient intake practices for trained individuals within a weekly microcycle. The occurrence and characteristics of exercise (training or competition) are proposed as a starting point to identify the duration of dietary analysis peri-training or competition (i.e. before, during, and after an exercise session) according to an individual’s intent and in agreement with the scientific evidence. The rationale for the PEN assessment is based on the evidence that in particular scenarios, nutrient intakes in proximity to an exercise session (training or competition) strengthen the outcomes of daily and within-a-day nutrient provision in achieving an individual’s goals (Thomas et al. 2016). Thus, the PEN assessment is applied if the scientific evidence supports the time-based energy and nutrient intakes either before, during or after an exercise session. Therefore, together with dietary data collection, the data of an exercise programme and an individual’s intent inform the PEN analysis. The PEN assessment may promote consistent quality of applied practice in sport and exercise nutrition. Additionally, the PEN assessment may allow for effective monitoring of habitual dietary practices of trained individuals specific to single or multiple training sessions and competitive events, within a weekly microcycle in a particular phase of the season. Moreover, the exploration of PEN practices in trained and athletic populations may inform the dietary standardisation in nutrient-exercise research projects and assist in the reduction of nutrient intakes variability by study participants. Since the development of methods was necessary to allow for the PEN assessment, that process is discussed below.
Figure 2 Proposed direct nutritional assessment for athletic populations

Note. 1Additional co-variables which are at the core of the peri-exercise nutrition (PEN) approach for athletes; 2Data collection and analysis arising from the PEN research question; 3Amount of energy and specific nutrients in food consumed can be calculated using food composition tables to assess average daily intake, actual daily intake, average intake per eating occasion and PEN, for comparison with athlete requirements in a personalised, periodised approach. 4Quality of the macronutrients, e.g. glycaemic index of carbohydrate or amino acids composition of protein in food cannot be assessed since quality exceeds current functionality of commonly used dietary analysis platforms. However, the sources of nutrient intakes can be examined based on food groups, e.g. plant versus animal sources of protein.

2.10.1. Development of PEN Assessment Methods

The development of the PEN methodology necessitated standardisation of terminology and advancement of existing dietary assessment tools, i.e. data collection, software customisation, data coding and proposition of novel data analysis. The methodology and methods used to investigate both traditional dietary and PEN assessment in this research thesis are described in Chapter 3. Based on the research studies provided in
the succeeding chapters of this thesis, the current status, challenges and future work required to advance the PEN assessment are discussed in Chapter 10.

2.10.1.1. Terminology

The terminology specific to the PEN approach and used in this thesis is defined in Table 5.

Table 5 Terminology specific to the PEN approach

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eating occasion (EO)</td>
<td>An intake of energy-containing (&gt; 0 kcal) food, fluids, including alcoholic beverages, and dietary supplements within a discrete, 30-minute timeframe. In the PEN approach predefined eating terminology, as used in traditional dietary assessment, e.g. main EO and snacks, was not used. Instead, the time of intake of food, fluids and dietary supplements was referenced. The time of an EO together with the time of an exercise session were used to calculate the proximity of energy and nutrient intakes to exercise sessions.</td>
</tr>
<tr>
<td>Distribution of EO</td>
<td>Range of time between two adjacent EO over the course of the assessed time. The distribution between the two EO is assessed if two EO are not separated by sleep time.</td>
</tr>
<tr>
<td>Distribution of nutrient intake</td>
<td>Range of time between intakes of the same nutrient from food, fluids and dietary supplements, over the course of the assessed time. The distribution between intakes of the same nutrient is assessed if two EO are not separated by sleep time.</td>
</tr>
<tr>
<td>Frequency of EO</td>
<td>Number of occurrences of EO consumed within the assessed time.</td>
</tr>
<tr>
<td>Frequency of nutrient intake</td>
<td>Number of occurrences of nutrient intake within the assessed time.</td>
</tr>
<tr>
<td>Phase</td>
<td>A timeframe or duration of dietary assessment before, during and/or after an exercise session.</td>
</tr>
<tr>
<td>Quantity of nutrient</td>
<td>A value, dose or amount of nutrient consumed from food, fluids and dietary supplements, within a given time, e.g. per EO, daily.</td>
</tr>
<tr>
<td>Quality of nutrients</td>
<td>A term specific to assessed nutrients, e.g. protein, carbohydrate.</td>
</tr>
</tbody>
</table>
### 2.10.1.2. Data Collection

A 7-day weighed dietary record ("pen-and-paper" or MS Excel file format) was used for food, fluid and dietary supplement data collection. The 7-day dietary record allowed for traditional dietary assessment and PEN assessment using the same data set. Additional information related to activities of daily living such as wake-up times and bedtimes were recorded in the designated place in a dietary log. Parallel to dietary recording, the process included data collection of exercise sessions and individuals’ aims in an exercise log, over the seven consecutive days. Table 6 identifies key extensions to exercise programme data collection, which were necessary to facilitate PEN assessment in trained individuals. The detailed information about data collection are described in Chapter 3, Section 3.6. Guidelines about recording dietary and exercise practices are provided in Appendix 1 and Appendix 2, respectively. The complexities and enhancements arising from the concomitantly recorded dietary and exercise data collection necessitated innovations to a standard nutritional analysis platform.

Table 6 Exercise log features supporting the PEN assessment

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase of season</td>
<td>Pre-Season</td>
<td>Self-reported phase of season by an individual.</td>
</tr>
<tr>
<td></td>
<td>In-Season</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off-Season</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not Applicable</td>
<td>Not competing, trained individual.</td>
</tr>
<tr>
<td>Category</td>
<td>Variable</td>
<td>Additional information</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Type of day¹</td>
<td>Rest</td>
<td>No reported exercise of any type (except for activities of daily living, e.g. housework).</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>Involved a voluntary exercise session (e.g. resistance, endurance, skill-based, team training), which was planned, structured and performed with a particular objective (e.g. maintain physical fitness, improve performance, improve body composition) (Caspersen <em>et al.</em> 1985).</td>
</tr>
<tr>
<td></td>
<td>Competition</td>
<td>Reported competitive event (e.g. race), when a trained individual or an athlete competed against other trained individuals or athletes.</td>
</tr>
<tr>
<td>Type of exercise</td>
<td>Resistance</td>
<td>If relevant, additional information (e.g. name of exercise, distance, speed or volume) within the type of training or competition was captured.</td>
</tr>
<tr>
<td></td>
<td>Endurance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Team</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skill-Based</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td></td>
</tr>
<tr>
<td>Exercise time and duration</td>
<td></td>
<td>Self-reported; time was kept in the 24-hour clock; duration was recorded in minutes.</td>
</tr>
<tr>
<td>Exercise intensity</td>
<td>0–10</td>
<td>Assessed with the Rating of Perceived Exertion Scale (Borg 1982); trained individuals rated their perceived exertion using Borg’s scale from 0 (rest) to 10 (maximal exertion), 30 minutes post-exercise (Foster <em>et al.</em> 2001).</td>
</tr>
<tr>
<td>Individual's intent</td>
<td></td>
<td>Self-reported; including short, medium and long-term goals, e.g. body composition, training adaptation and competition performance.</td>
</tr>
</tbody>
</table>

*Note.* ¹Day is considered to be 24 hours from 00:00 (midnight) to 23:59. PEN–Peri-exercise nutrition.
2.10.1.3. Nutrition Analysis Software Customisation and Data Coding

Nutrition analysis software should allow practitioners to perform comprehensive data coding. Working collaboratively with a Nutritics Ltd. (Ireland) nutrition analysis software developer, the existing data entry platform was reviewed and advanced to represent those nuances of trained individuals’ and athletes’ lifestyles that are integral to dietary analysis. The author particularly wished to analyse the adequacy of PEN where the specific exercise stimulus was at the core of the assessment, and the dietary complexities of energy and nutrient intakes were assessed (Figure 2). The addition of data entry fields (termed custom fields) allowed for the entry of unique information for each EO; the date and time of EO consumption, type and time of exercise session, type of day and phase of season were coded and added to custom fields and then used in the PEN analysis. Other additional information recorded in custom fields, such as place of EO preparation and type of pre-defined EO, were specific to traditional assessment, not to the PEN assessment. A Standard Operating Procedure (SOP) was devised to standardise data entry using Nutritics Ltd. (Ireland) software (Appendix 3). The SOP provided information on how to create participant profiles, add a daily log, recipes and food products. The SOP accommodated requirements for coding the information that allowed for traditional and the PEN analysis. The guidelines on how to code both traditional and PEN analysis-specific dietary and exercise information into custom fields were available in the SOP as well. Details on training and competition events (e.g. RPE, intent) from the exercise log (Table 6 and Appendix 2), wake-up times and bedtimes were available for analysis in an additional MS Excel file.

2.10.1.4. Data Analysis

The data output file for the PEN analysis from the Nutritics Ltd. (Ireland) software does not differ from the standard output file for a daily or per pre-defined EO analysis. Hence, the data output file had to be modified to facilitate the PEN analysis. With data export, all food, fluids and dietary supplements, and information from custom fields were shown in separate columns. A list of food, fluids and dietary supplements together with their nutritional information were summarized into EO, using pivot tables and Visual Basic for Applications functions (Microsoft Excel 2016). Information from the additional fields was combined into a file in which each EO could be distinguished by unique information such as a subject’s code, date and time of record. From the additional MS Excel file, information about each participant’s goals,
wake-up times and bedtimes were added to an EO output file. Body mass information was then added to demonstrate nutrient intakes relative to body mass. The additional information used for the PEN analysis included date and time of EO, type of day (i.e. TD, RD, CD), type and time of exercise performed, an individual’s intent and phase of the season. Using pivot tables, available text, logical, statistical, and Visual Basic for Applications functions (Microsoft Excel 2016), the time of exercise session was placed as a starting point of analysis. The time of nutrient intakes was calculated in proximity to an exercise session. To calculate the time of EO consumption before or during an exercise session, the EO was subtracted from the start time of an exercise session. Similarly, to calculate the time of an EO consumed after an exercise session, the time of EO was subtracted from the end time of an exercise session. According to the scientific evidence, only nutrients (consumed in proximity to a specific type of exercise session and within the recommended time frame for intake) that support the intended outcome were included in the PEN analysis.

2.10.1.5. Evidence-Based Recommendations

In the PEN approach, the assessment of adequacy of energy and nutrient intakes in proximity to an exercise session and in support of individuals’ intent is based on the scientific evidence. The optimised energy and/or nutrient intake PEN prescription can be proposed if the evidence shows that the energy and/or nutrient intake patterns in proximity to exercise optimise the intended outcome (e.g. adaptation, recovery). The available sport nutrition guidelines (Thomas et al. 2016; Kerksick et al. 2017) and research studies, which support the PEN prescription, can be used to advance daily dietary recommendations, data collection and analysis in trained and athletic populations. The PEN prescriptions pertain mainly to macronutrient intakes for resistance and endurance types of exercise (Thomas et al. 2016; Kerksick et al. 2017). While devising the PEN prescription, type, quantity, quality, distribution, frequency, and time of nutrient intakes in proximity to an exercise session should be considered. The PEN prescription ought to be specific to exercise session characteristics (e.g. type, duration, intensity) and an individual’s intent.

The examples of evidence-based PEN recommendations are presented in Chapter 4 for resistance and Chapter 6 for endurance exercise. The PEN prescription might differ depending on the individual’s dietary requirements, exercise and intent. When the scientific evidence lacks the PEN prescription, and analysis of the adequacy of energy
and nutrient intakes cannot be offered either. In the absence of PEN assessment, only the traditional daily and per pre-defined EO assessment can be performed. Despite progression in the field of sport and exercise nutrition, further advancements and clarification of guidelines are required to support time-, exercise- and intent-specific dietary assessment (Jeukendrup 2017).

2.10.1.6. Considerations of the Complexity of the PEN analysis

The adequacy of daily and peri-exercise dietary intakes within a weekly microcycle contributes to long-term nutrient requirements to support exercise programme outcomes, within a mesocycle and macrocycle. Once the PEN prescription is defined to assess the dietary practices of a single exercise session, the complexity of one’s exercise programme should be considered. There might be multiple dietary solutions as a result of the various exercise modes (including training sessions and competitive events) and one’s goals, which might either have supportive, neutral or contradictive effects on desired outcomes. Hence, the most profitable and viable dietary scenario to support an individual’s main intent should be proposed. For example, in a scenario when the phase of PEN analysis of one session overlaps with the time of another exercise session, the practitioner’s dietary analysis decisions could be guided by answering the questions posed in Figure 3. An example of decision process to conduct PEN analysis of multiple training sessions is provided in Chapter 7 based on Figure 3.

Chapter 4 and Chapter 6 present examples of dietary recommendations in traditional and PEN assessment, and possible evidence-based nutrient intake considerations for resistance and endurance exercise in context of their intent. Examples of dietary analysis using the PEN method for resistance and endurance exercise were described in Chapter 5 and Chapter 7 for resistance and endurance exercise, respectively.

Overall, PEN practices complement daily recommended energy and nutrient intakes to support long-term goals. A practitioner or researcher might assess the patterns and/or adequacy of energy and nutrient intakes in proximity to an exercise session, which are of particular interest in data recorded by either an individual or a group of individuals. The rationale to assess the adequacy of nutrient intakes for a particular exercise session and intent might be driven by

- a research question,
- a prescription of dietary standardisation in a research setting.
the gap in the literature about the habitual nutrient intakes of a group of individuals, and

- an individual’s motivation or difficulties in nutrient provision for a particular type of exercise session and goals.

Exercise programmes and individuals’ goals are unique. The nutrient intakes assessment (including their type, quantity, quality, time, distribution and frequency) using the PEN approach is comprehensive. Therefore, at the time of this thesis, it was feasible to assess nutrient intakes that are specific to one type of exercise and goal in a group of trained individuals. The PEN analysis specific to each exercise session and an individual’s intent is assessed on a case study basis within a weekly microcycle.

Figure 3 Decision tree for PEN data analysis

*Note. EO–Eating occasion; PEN–Peri-exercise nutrition.*
2.10.2. Dietary Prescription and Standardisation Using PEN Assessment Outcomes

Information about habitual nutrient intakes by trained individuals and athletes can inform dietary prescription in sport and exercise nutrition practice and research. The findings of suboptimal PEN practices may allow practitioners, trained individuals or athletes to find the most feasible solution that meets dietary recommendations specific to an exercise session and one’s intent. The PEN approach could be used as an educational tool for trained individuals and athletes to promote optimised EO consumption in proximity to an exercise session. Further study could investigate whether modifications of only suboptimal practices rather than prescribing a meal plan could increase individuals’ knowledge of optimising nutrient intakes and decrease the burden of implementing new patterns of food intakes. In research settings, understanding of food preferences and habitual nutrient intakes of study participants allows for planning a dietary standardisation that meets their food preferences, reduces nutrient intake variability and increases participants’ dietary compliance. The successful, carefully planned and tailored to research study dietary standardisation is a more efficient approach, in comparison to dietary replication (Jeacocke and Burke 2010; El-Chab et al. 2016). Moreover, dietary standardisation may minimise the effect of nutrient intake variability on outcomes in nutrient-exercise intervention studies (Close et al. 2019). The knowledge of participants’ habitual dietary practices can be incorporated into dietary standardisation in two ways. Firstly, the information allows recreating the habitual practices of a group within the nutrient-exercise intervention study. Secondly, dietary standardisation can be planned according to optimal dietary requirements while considering participants’ food preferences where appropriate (Close et al. 2019).
Chapter 3
Methodology and Methods
3.1. List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM</td>
<td>1 Repetition maximum</td>
</tr>
<tr>
<td>CD</td>
<td>Competition day/s</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>DXA</td>
<td>Dual-energy X-ray absorptiometry</td>
</tr>
<tr>
<td>EEE</td>
<td>Exercise energy expenditure</td>
</tr>
<tr>
<td>EA</td>
<td>Energy availability</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>FFM</td>
<td>Fat-free mass</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>Mdn</td>
<td>Median</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RD</td>
<td>Rest day/s</td>
</tr>
<tr>
<td>RT</td>
<td>Resistance training</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SOP</td>
<td>Standard operating procedure</td>
</tr>
<tr>
<td>TD</td>
<td>Training day/s</td>
</tr>
<tr>
<td>VO2max</td>
<td>Maximal oxygen uptake</td>
</tr>
</tbody>
</table>

3.2. Abstract

This chapter describes the methodology used for dietary and exercise data collection, data entry, and analysis using both traditional and exercise session-specific analysis. Resistance-trained (aged 18 to 40 years) and endurance-trained (aged 18 to 45 years) males were recruited for the research studies. The participants’ anthropometry profiles were assessed using body mass, height and body composition according to the standardised protocol. The 7-day weighed dietary and exercise records were devised to capture the data. Comprehensive data collection necessitated the development of a standard operating procedure (SOP) protocol to work with the existing nutrition analysis software Nutritics Ltd. (Ireland) for data coding and entry. The dietary output software file was modified by the author to enable analysis per pre-defined eating occasion (EO) and peri-exercise nutrition (PEN) analysis. The PEN data were analysed according to scientifically determined standards of exercise-, time- and intent-specific nutrient intakes. All data were checked for normal distribution and analysed according to individuals’ aims. The summary of quality control for the assessed data is provided.
3.3. Ethical Approval

Ethical approvals were granted for the studies by the Faculty of Education and Health Sciences Research Ethics Committee (2016_12_09 EHS, 2017_03_19 EHS), University of Limerick. Participants were familiarised with the study protocol and informed about the risks and benefits of participation in the study. Participants provided written informed consent.

3.4. Participants

3.4.1. Study 1

For the study discussed in Chapter 5, a cohort of male individuals, 18–40 years, resistance-trained [defined as 0.5 years of continuous resistance training (RT), ≥ 3 h·wk$^{-1}$ before starting the data collection], was recruited from the local community to participate. Participants self-reported as being injury- and illness-free. They were not taking any prescriptive medications, nor did they have a history of chronic diseases. Participants were not dieting (for weight loss) before the study commencement or planning to diet for the duration of the study. The cohort recruited sought to support muscle hypertrophy and strength gain and engaged in RT for this purpose alone.

3.4.2. Study 2

The dietary assessment of male individuals, 18-45 years, endurance-trained [maximal oxygen uptake (VO$_{2}$max) ≥ 55 ml·min$^{-1}$·kg$^{-1}$] and participating in competitive endurance events is presented in Chapter 7. Participants self-reported as being injury- and illness-free. They were not taking any prescriptive medications, nor did they have a history of chronic diseases. The data analyses were performed on a case study basis according to individuals’ exercise programmes and goals.

3.4.3. Study 3

The research study described in Chapter 8 recruited a cohort of male individuals to participate. Participants were males aged 18 to 35 years, with at least six-months of RT experience (> 3 h·wk$^{-1}$) before study commencement, able to competently perform a 1.25 kg·kg$^{-1}$ barbell back-squat at 1 repetition maximum (1RM), and who reported no current injury, illness, medication or history of chronic disease, while being lactose tolerant.

Summary of characteristics of the subjects for all three studies is presented in Table 7. In order to better present the application of PEN, the chronology of research studies in
this thesis was set up as Study 1–Study 3, while Study 2 was the last study completed during this doctoral programme.

Table 7 Summary of subject characteristics from all three studies

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Primary exercise</th>
<th>Age (y)</th>
<th>Body Mass (kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1 (Chapter 5)</td>
<td>37</td>
<td>Resistance</td>
<td>26.2 (5.5)</td>
<td>81.9 (11.3)</td>
<td>180.9 (6.8)</td>
</tr>
<tr>
<td>Study 2 (Chapter 7)</td>
<td>3</td>
<td>Endurance</td>
<td>32.0 (9.5)</td>
<td>70.8 (12.9)</td>
<td>179.4 (13.1)</td>
</tr>
<tr>
<td>Study 3 (Chapter 8)</td>
<td>23</td>
<td>Resistance</td>
<td>23.7 (3.9)</td>
<td>79.7 (12.6)</td>
<td>180.8 (6.4)</td>
</tr>
</tbody>
</table>

Note. Data are means (SD).

3.5. Assessment of Anthropometry

Body mass (Tanita MC, 180-MA, Tanita United Kingdom Ltd.), height (Seca Birmingham, United Kingdom) and whole-body composition [dual-energy X-ray absorptiometry (DXA) scans, Lunar iDXA™, GE Healthcare] were measured prior to the dietary recording phase. The body composition assessment was performed in agreement with the official position of the International Society for Clinical Densitometry (Shepherd et al. 2013). As described by Toomey et al. (2016), participants were asked to refrain from exercising 12 hours before testing, and from consuming food and energy-containing beverages from 22:00 hours the previous night. One hour prior to the body composition assessment, participants were asked to drink 500 ml of water and empty their bladder immediately before the appointment. Body composition was analysed using En-CORE™ v.14.1 software. Body mass was measured to the nearest 0.1 kg. Height was measured to the nearest 0.1 cm and participants’ heads remained in the Frankfurt Plane.

3.6. Dietary, Exercise and Complementary Data Collection

The author met with recruited participants on two occasions. During the first appointment, participants were familiarised with the 7-day weighed dietary and physical activity data collection procedures. During a second appointment, returned recording sheets were screened for completeness and discussed individually with participants.
Each participant received a printed or digital copy (according to their preferences) of a 7-day weighed dietary record and a 7-day physical activity log (Figure 4), together with their written guidelines (Appendix 1). A 7-day dietary intake and exercise programme record consisted of 22 pages (including cover page). A one-day record consisted of three pages. Participants were asked to record date, wake-up time and bedtime every day. Information about foods and fluids consumed was recorded in a table. The information required from participants included time of intake, list of ingredients, quantity consumed, quantity of leftovers, cooking method, and place of preparation or purchase. The last column of the table allowed participants to provide additional comments. The list of ingredients included a brand name and a version of a product (e.g. wholegrain/white bread, whole/skimmed milk, or 6%/15% minced beef). In the same table, participants could provide detailed information about dietary supplements consumed (i.e. name, brand, dose, time of consumption) and co-ingested food and/or fluids.

The last page of the daily record provided additional space to record recipes. One third of this page was designated to record dietary supplement intake if participants did not record it with consumed foods and beverages. The last-third of this page related to participants’ daily exercise programmes. In Study 1, the information collected included exercise type, time, duration, and other exercise session characteristics, e.g. weights lifted in kilograms and/or as a percentage of one’s 1RM for resistance-trained individuals.
Figure 4 7-day weighed dietary intake record

*Note. One day is presented as an example.*
During Study 1, the PEN assessment was performed for RT only. Therefore, participants were asked about the rationale for performed RT and phase of their season. In the first study, information about exercise programmes was collected in a designated place in the dietary record. Based on this process, the importance of recording more details about exercise programmes for PEN assessment and prescription was acknowledged (Chapter 10, Section 10.4). In the second research study, the exercise programme data were collected in a separately designed exercise log in the MS Excel format. The additional information captured in the exercise log was the aim and Rating of Perceived Exertion using Borg’s Scale (Borg 1982; Foster et al. 2001) for each exercise session. Participants received guidelines on how to complete the exercise log (Appendix 2). In addition, energy expenditure during the 7-day recording was collected during Study 2 using the SenseWear® Pro3 Armband. The Sensewear® Armband was initialised and participants’ characteristics were entered (date of birth, body mass, height, sex, handedness and smoking status) using the Body Media® Sensewear® 6.1 Software. Endurance-trained individuals wore the SenseWear® Armband according to the user manual.

Food grade weighing scales (DYMO M2®, USA) were provided to all participants before data recording for the duration of the study. The weighing processes included food (in grams), fluids and dietary supplements (in grams or ounces) consumed, and leftovers. All data recording issues were solved with participants before and during data recording. Troubleshooting related to data recording included scenarios where participants were not

- able to weigh each ingredient (e.g. in a restaurant). Participants were encouraged to provide quantity in household measures and send images of food eaten via email. Images were attached to dietary records.
- able to identify all ingredients from an EO. Participants were asked to provide as much information as possible, including images, labels, wrapping and a link to relevant product information online (e.g. restaurant, supermarket). This information could be provided in the dietary record, sent via email or brought in person during the appointment following the recording phase.
- certain how to record ready-to-eat meals or less popular food products. Subjects were asked to provide information about time eaten, name of product, brand name, cooking method and leftovers, and send an image of each label
that provides the name of product, brand name, weight, ingredients’
information and nutritional value of a product. Participants could also bring
the empty package for the next appointment.

If the additional information was forwarded via email or in person, participants were
asked to acknowledge it in a dietary log. The author explained the importance of
accurate and precise data recording. Participants were informed that the quality of the
feedback they would receive after study completion depended on the quality of the
collected data. The author and participants decided the start and end date of the data
record. Participants received reminders about the starting date of recording and the
follow-up appointment via phone call or email. Participants confirmed that the data
were recorded during a habitual dietary, physical activity and exercise period.

Returned 7-day dietary records, together with exercise logs were screened for
completeness and discussed individually with each participant.

3.7. Data Entry
The comprehensive dietary and exercise data record necessitated the development of
new custom fields in an existing nutrition analysis software, i.e. Nutritics Ltd.
(Ireland). This advancement was facilitated on the University of Limerick research
accounts by Nutritics Ltd. to allow data entry and analysis that were not heretofore
possible in this platform. The SOP was devised to systematise dietary and exercise
data coding and entry for the data fields (Appendix 3). The additional information
captured in the new custom fields was date, type of day, time of EO, EO descriptor,
place of EO preparation, phase of a season, type and time of an exercise session. To
follow a traditional dietary assessment, each EO received designated classifications
that are defined using times and energy values (described in Chapter 2, Section 2.9,
and presented in Table 4). To classify an EO for PEN analysis, the date, time of
consumption, type of day, type and time of exercise sessions, and phase of season were
coded into the software. The additional information regarding training and competitive
events, an individual’s training intentions, daily wake-up time and bedtime were also
entered into a Microsoft Excel 2016 file from participants’ records, to allow for PEN
analysis. The wake-up times and bedtimes were collected to calculate the distribution
of EO within waking hours.
3.8. Data Analysis

3.8.1. Development of Data Output Files

The data output file exported from Nutritics Ltd. (Ireland) software, lists individual food ingredients and products, fluids and dietary supplements in rows within one column. The amount of nutrients, and the additional information that is entered into custom-designed fields and other information (e.g. food databases) are provided in columns and are assigned to each row in an output file. The traditional dietary assessment is based on output files that summarise daily and pre-defined EO. However, Nutritics Ltd. (Ireland) software did not provide the output file with pre-defined EO, nor time-, aim-, and exercise-centred nutrient intakes output file used for PEN. The author developed the output file to enable the assessment of energy and nutrient intakes of a pre-defined EO and the time-based analysis in proximity to exercise sessions. After the data were checked for errors, the customisation of the output file involved the following steps:

1. The file with pre-defined EO was created by summing up energy and nutrient intake values of entered foods, fluids and dietary supplements specific to an EO. Each EO was unique due to participant’s code, date, time, type of day, phase of season and assigned EO descriptor (see Chapter 2, Section 2.9. and Section 2.10.1.4.).

2. The detailed information from exercise logs, wake-up times and bedtimes from an additional Microsoft Excel file were added to the file with a pre-defined EO. Each participants’ body mass was added to this file to calculate energy and macronutrient intakes relative to body mass.

3. The comprehensive file with a pre-defined EO was transformed into the PEN file. The PEN file was created by placing the time of exercise sessions as a starting point for data analysis. The start time of an exercise session was used to calculate the time of nutrient intakes before and during a session. The end time of an exercise session was employed to calculate the time of nutrient intakes after exercise. The duration of the PEN analysis (e.g. pre-, during, and post-exercise session) was defined based on scientific evidence. The cases are discussed in Chapter 4 for Study 1 and in Chapter 6 for Study 2. Only EO, which were consumed within the defined PEN phase of assessment, were
included in the PEN analysis (e.g. within 24 hours post-RT) (See Chapter 2, Section 2.10.1.5.).

Furthermore, the file for daily dietary analysis was created by summing up the nutritional information of all foods, beverages and dietary supplements consumed each day. Participants’ codes, date, type of day, and phase of season were used to create the file. The author used pivot tables, available text, logical, statistical, and Visual Basic for Applications functions in Microsoft Excel 2016 to transform data into the required formats. Moreover, the energy expenditure data recorded during the second research study were exported using the Body Media® SenseWear® 6.1 Software and analysed in Microsoft Excel 2016.

3.8.2. Statistical Analysis

In all three studies (Table 7), the statistical analyses were carried out with the IBM Statistical Package for the Social Sciences, version 25.0 (IBM SPSS Inc., Chicago IL, USA) and Microsoft Excel 2016. Data were tested for normality using the Shapiro-Wilk test ($N < 100$). Additionally, the Kolmogorov-Smirnov test, in conjunction with a histogram, was used to examine variables of larger sample sizes ($N > 100$). The data were presented as means ($M$) and standard deviations ($SD$) or medians ($Mdn$) and 25th and 75th percentiles (25th–75th percentiles), as appropriate for descriptive statistics. All data were analysed within 95% of confidence interval (95% CI).

3.8.2.1. Traditional Dietary Analysis

The daily and/or per EO recommended energy availability and nutrient intakes are provided in Chapter 4 for RT (Study 1 and Study 3) and Chapter 6 for endurance exercise, i.e. training and competition events (Study 2). In Study 2, exercise energy expenditure (EEE) was measured by the SenseWear® Pro3 Armband. When no EEE data could be provided from the device due to an error or an ET session in water, the EEE was calculated using the Ainsworth’s tables (Ainsworth et al. 2011), according to the exercise session reported in the physical activity logs. Daily energy intake, EEE and fat-free mass (FFM) information allowed calculation of participants’ daily energy availability (EA). Based on the EA equation $[EA = (Energy \ intake - EEE) \cdot FFM^{-1}]$ (Heikura et al. 2018b), daily requirements of energy intake were calculated for each participant. Once the daily recommended energy, protein and fat intakes were known for each participant, the range of carbohydrate intake was calculated per diem. The adequacy of nutrient intakes relative to intake guidelines was expressed as a percentage.
(%) and as the number \((N)\) of participants, specific for 7 days, training days (TD), rest days (RD), competition days (CD), and per EO where appropriate. Dietary intake was considered as adequate when reported values met the recommended dietary intake ranges.

3.8.2.2. Peri-Exercise Nutrition Analysis

The patterns and/or adequacy of nutrient intakes in proximity to exercise session were examined according to dietary recommendations provided in Chapter 4 for RT and Chapter 6 for endurance exercise. While assessing adequacy, data were expressed as a percentage (\%) and as the number of cases \((N)\). The dietary intake was considered as adequate when it was within the recommended dietary intake ranges.

3.9. Evidence-Based Set of Recommendations

The traditional dietary assessment methods include mean daily and per EO energy and nutrient intakes for the 7-day record, TD, RD and CD. Daily and per EO nutrient intakes were compared to recommendations, as described in Chapter 4 for resistance-trained subjects. Daily reported energy and macronutrient intakes were compared to recommendations for endurance-trained subjects, as summarized in Chapter 6. The adequacy of nutrient intakes in proximity to a specific exercise session and according to an individual’s exercise goals was assessed within the PEN approach (see Chapter 2, Section 2.10.).

This time-, training- and intent-orientated dietary assessment was informed by scientific evidence. Only the nutrients, which consumption in proximity to an exercise session supported an individual’s intent (e.g. protein intake in support of muscle hypertrophy post-RT) were included in the PEN prescription and analysis. The PEN recommendations specific to resistance exercise were discussed in Chapter 4. The PEN recommendations for endurance exercise were discussed in Chapter 6. If scientific evidence did not support nutrient timing in proximity to a specific exercise session or intent, only the traditional dietary assessment was performed.

3.10. Summary of Quality Control for Data Collection and Data Coding

To ensure the quality of data collection and analysis processes, a number of quality procedures were implemented. The procedures ensured that participants

- met with the same researcher on two to three occasions,
- received a reminder of the start date of data collection, the day before its commencement,
were in contact with a researcher to trouble-shoot any data collection-related issues at the time of data collection,
were required to not improve or change their dietary practices during the time of record, and
confirmed that the data represented habitual dietary intake according to their weekly exercise plan.

Additionally,
data were collected and checked for completeness by the same researcher,
data were entered into software according to a developed SOP for Nutritics Ltd. (Ireland) (Appendix 3), and
random dual entries of food records were performed to identify and reduce bias.
Chapter 4
Dietary Considerations in Support of Resistance Training Intent
4.1 List of Abbreviations

1RM One repetition maximum
4E-BP1 Eukaryotic initiation factor 4E-binding protein 1
AI Adequate Intake/s
AKT Serine/threonine-specific protein kinase
DRI Dietary Reference Intake/s
EA Energy availability
EAA Essential amino acids
EO Eating occasion/s
FFM Fat-free mass
HMB β-hydroxy-β-methylbutyrate
M Mean
MPS Muscle protein synthesis
mTOR Mammalian target of rapamycin
NEAA Non-essential amino acid/s
p70S6K p70 ribosomal protein S6 kinase
PEN Peri-exercise nutrition
RDA Recommended Dietary Allowance/s
RT Resistance training
SD Standard deviation
TEI Total energy intake/s

4.2. Abstract

Nutrient intake can enhance adaptation to resistance training (RT), such as gains in muscle mass and strength, and can support fat loss in the presence of RT. Appropriate daily energy and macronutrient intakes may enhance training adaptation and body composition long term. Moreover, time-dependent protein intake has been shown to have a positive effect on muscle hypertrophy and fat loss in the presence of RT. This chapter offers a scientific, evidence-based review about energy and macronutrient intakes in support of muscle hypertrophy, strength gain and fat mass loss with concurrent maintenance of muscle mass, in the presence of RT. Furthermore, micronutrient intake recommendations are summarised in support of an individuals’ health. Additionally, the focus is set on a key nutrient, protein, and its optimal intake patterns [quantity, quality (source), time, distribution, frequency] in support of RT.
adaptation and fat loss. Lastly, dietary supplement intakes, such as creatine, caffeine, omega-3 fatty acids and selected amino acids were reviewed in the context of optimizing the adaptation to RT. In conclusion, the proposed dietary prescription is used as a reference criterion to assess the adequacy of nutrient intakes of resistance-trained individuals in Chapter 5.

4.3. Introduction

Skeletal muscle has the ability to adapt to exercise training stimuli. Exercise adaptation depends on training volume, frequency and intensity (Hawley 2008). The principal adaptation to RT performed with either free weights, exercise machines or the use of gravity against body mass, results in muscle fibre (myofiber) hypertrophy and strength gain (Knuttgen and Komi 2003). Moreover, adaptation to RT occurs at two levels, acute (lasts from minutes to hours) after each repeated exercise session and long-term (lasts from hours to days), as a result of the cumulative effect of cellular adaptation (Bolster et al. 2004). Optimal adaptation to RT is determined by appropriate nutrition. The key nutrient in this process is protein (Phillips et al. 2005; Churchward-Venne et al. 2012b; Witard et al. 2016). Optimised protein intake per eating occasion (EO), either pre- or post-RT session, results in superior muscle protein synthesis (MPS) than protein intake or RT session alone (Phillips et al. 2005; Moore et al. 2009b). Additionally, an RT session together with dietary support is performed to induce fat mass loss, with the concurrent aim of maintenance of lean tissue mass or muscular strength (Donnelly et al. 2009; Garthe et al. 2011).

This chapter offers an evidence-based literature review of energy and nutrient intakes both per day and per EO. Moreover, this review demonstrates the evidence for peri-exercise nutrition (PEN) prescription in proximity to RT and in agreement with individual’s goals while performing RT. Daily, per EO and PEN dietary prescriptions consider energy, type, quantity, quality, timing, distribution, frequency of nutrient intakes and co-ingestion of nutrients, according to the scientific evidence. No dietary prescription was made specific to RT and individual’s goals, where there was no substantial evidence to offer dietary intake recommendations. Pursuant to the optimal dietary prescription reported here, the dietary analysis of a group of resistance-trained individuals is presented in Chapter 5.
4.4. Muscle Hypertrophy
A single bout of RT or protein intake results in the activation of mammalian target of rapamycin (mTOR), i.e. a principal mechanism which initiates ribosomal translation. The post-RT state promotes activation of serine/threonine-specific protein kinase (AKT) and indirectly mTOR. The increased pool of available amino acids increases the level of circulating insulin and phosphorylates mTOR. The mTOR phosphorylates eukaryotic initiation factor 4E-binding protein 1 (4E-BP1) and phosphorylation of p70 ribosomal protein S6 kinase (p70 S6K), in turn increase MPS and promote cell growth. Long term, this repeating mechanism enhances muscle hypertrophy (an increase in muscle cross-sectional area), and strength. (Bolster et al. 2004; Camera et al. 2016) (Figure 5).

Figure 5 Principles of adaptation to RT stimuli supported by amino acid intake

Note. AKT–Serine/threonine-specific protein kinase; mTOR–Mammalian target of rapamycin; 4E-BP1–Eukaryotic initiation factor 4E-binding protein 1; p70S6K–p70 ribosomal protein S6 kinase; MPS–Muscle protein synthesis.

4.5. Strength Gain
Muscle hypertrophy positively relates to an increase in maximal force production, i.e. strength gain post-RT (American College of Sports Medicine 2009). However, strength gain can be promoted without muscle hypertrophy (Loenneke et al. 2019). The proposed mechanism that develops strength gain is based on a neuromuscular
adaptation to RT via the central nervous system (Carroll et al. 2001; Gabriel et al. 2006; American College of Sports Medicine 2009; Loenneke et al. 2019). The promotion of strength gain via neural adaptation requires a progressive increase in weight lifted during RT (American College of Sports Medicine 2009). Studies designed to investigate gain in strength without muscle hypertrophy are scarce and thus, further work in this field is required (Loenneke et al. 2019). Dietary support that optimises muscle hypertrophy can concurrently support strength gain. However, less is known if the patterns of nutrient intakes have an additive effect to total daily nutrient intakes in support of strength gain only.

4.6. Resistance Training-Induced Fat Mass Loss
The physical activity strategies for body mass loss and maintenance consider resistance exercise as part of the intervention (Donnelly et al. 2009). The possible effect of RT on energy expenditure and body fat loss is presented in Figure 6. Generally, RT alone results in lower energy expenditure and fat utilisation than aerobic training (Willis et al. 2012). Regardless of dietary restrictions, RT results in a reduction of 3% of initial body mass (Donnelly et al. 2009). Nevertheless, RT maintains muscle mass greater than aerobic training (Willis et al. 2012). Together, RT with an appropriate dietary regimen (discussed in subsequent sections) is an effective method to reduce or maintain body mass, reduce fat mass, and to restrict muscle mass loss or enhance the lean tissue mass accretion (Doi et al. 2001; Layman et al. 2005; Willis et al. 2012).

Figure 6 Possible effects of RT on energy expenditure and body fat loss, adapted from Donnelly et al. (2009)

4.7. Dietary Considerations
In this section, energy, macronutrient, micronutrient and dietary supplement intake strategies that support the intended outcome of RT, i.e. muscle hypertrophy, strength gain and fat mass loss, are evaluated according to the scientific evidence. The results of dietary considerations are summarised in the conclusions section (4.8.) and applied to dietary analysis in Chapter 5.
4.7.1. Energy

Exogenous sources of energy from macronutrients are required to meet the demands of metabolic functions, activities of daily living and exercise energy expenditure (Westerterp 2017). However, inadequate energy intake may cause suboptimal adaptation to RT, not only due to the higher oxidation rate of protein but also because of the inhibition of mTOR phosphorylation post-exercise (Rennie et al. 2004). In addition, Rennie and Tipton (2000) and Wolfe (2000) showed that RT performed in the fasted state enhances muscle protein breakdown (MPB) and suppresses MPS post-exercise. However, it is challenging to measure energy expenditure during resistance exercise in free-living conditions, despite the advancements in portable technologies. Scheers et al. (2012) considered wearable devices to be an accurate method of assessment of activities of daily living if worn at a minimum over three weekdays and two weekend days (Scheers et al. 2012). Nevertheless, wearable devices result in underestimation or overestimation of energy expenditure and often do not reflect the load being moved during RT (Benito et al. 2012). Mazzetti et al. (2011) examined energy expenditure for light [48% of one repetition maximum (1RM)], moderate (50% of 1RM), heavy (72% of 1RM) and heavy load-matched (72% of 1RM) RT protocols by measuring oxygen consumption during an RT session and then 60 minutes post-exercise. However, the measurement of oxygen consumption may not always be viable to use in practical settings, hence the Ainsworth’s tables might be a useful alternative to estimate exercise energy expenditure during RT in free-living individuals (Ainsworth et al. 2011). Information about exercise energy expenditure, together with daily energy intake, are essential components of energy availability (EA). EA might not be feasible to calculate if either the information about exercise energy expenditure, energy intake or fat-free mass (FFM) is missing.

The EA term was introduced to quantify the energy available for metabolic function (Loucks et al. 2011). The recommended EA for optimal health and adaptation to training stimuli is ≥ 45 kcal·kg\(^{-1}\) FFM. Energy availability between 30–45 kcal·kg\(^{-1}\) FFM is recommended when an individual goal is to decrease body mass or fat mass (Loucks et al. 2011). The daily maintenance of less than 30 kcal·kg\(^{-1}\) FFM results in physiological dysfunction and suboptimal training adaptation (Loucks et al. 2011; Fagerberg 2018). Therefore, when the aim is to reduce body mass or fat mass, a gradual body mass loss by 0.5–1.0 kg weekly (Garthe et al. 2011) will allow an individual to
maintain EA above 30 kcal·kg⁻¹ FFM (Melin et al. 2019). The gradual body mass loss can be achieved by a moderate daily energy deficit of 500–1000 kcal (Garthe et al. 2011). A dietary regimen with low (1000–1200 kcal·d⁻¹) or very low (400–800 kcal·d⁻¹) energy intake long-term has negative consequences for an individual’s health (Aragon et al. 2017). Moreover, energy intake between 400 and 1200 kcal daily does not provide a minimum of 30 kcal·kg⁻¹ FFM to support optimal physiological functions. Additionally, in research studies by Garthe et al. (2011) and Longland et al. (2016), muscle hypertrophy (Garthe et al. 2011; Longland et al. 2016) and strength gain (Garthe et al. 2011) were achieved in the hypocaloric condition in recreationally active individuals and elite athletes. To attain this muscle hypertrophy and strength gain, daily energy deficit between 19 and 40% (~470–1000 kcal) of total energy intake (TEI) and higher daily protein intake (1.4–2.4 g·kg⁻¹·d⁻¹) were applied (Garthe et al. 2011; Longland et al. 2016). The duration of dietary intervention lasted between 5 and 10 weeks and resulted in ~4–6% of body mass and ~5–6% of fat mass loss. The EA was estimated to be > 30 kcal·kg⁻¹ FFM during rest days. Information about exercise energy expenditure was not provided for calculation of EA during training days (Garthe et al. 2011; Longland et al. 2016).

Pasiakos et al. (2010) showed that a 20% energy deficit (~500 kcal) may decrease muscle protein synthesis by 19% after the first 10 days of intervention. However, it should be considered that EA during this time was ~1930 kcal (~34 kcal·kg⁻¹ FFM during days without exercise) and daily protein intake was 1.5 g·kg⁻¹·d⁻¹. No information was given about how much energy individuals expended during habitual exercise sessions during the hypocaloric condition (Pasiakos et al. 2010). However, based on body composition characteristics provided at baseline and energy intake during the dietary intervention, exercise energy expenditure of ~270 kcal would result in EA below 30 kcal·kg⁻¹ FFM. Areta et al. (2014) showed that in the hypocaloric conditions when EA was 30 kcal·kg⁻¹ FFM, an RT session restores the myofibrillar fractional synthetic rate (0.019%·h⁻¹) to values when EA was 45 kcal·kg⁻¹ FFM (0.026%·h⁻¹, an increase of 27%). Protein intake post-RT enhanced the rate of myofibrillar protein synthesis further. The 30 g of whey protein intake increased MPS for another 34% (to 0.038%·h⁻¹) (Areta et al. 2014).

In summary, EA of ≥ 45 kcal·kg⁻¹ FFM supports optimal physiological functions, training adaptation and sports performance. In hypocaloric conditions, energy
availability 30–45 kcal·kg\(^{-1}\) FFM can be considered as supportive of maintenance or increase of muscle mass and strength when daily protein intake is 1.6–2.4 g·kg\(^{-1}\)·d\(^{-1}\). Additionally, protein intake of 30 g of whey protein post-RT further supports muscle hypertrophy during dietary restrictions. Therefore, dietary energy deficit of 500–1000 kcal·d\(^{-1}\), which results in gradual body mass loss, allows maintaining EA above 30 kcal·kg\(^{-1}\) FFM. The assessment of energy expenditure during RT might be a limiting factor in assessing an individual’s EA.

### 4.7.2. Protein

Protein is a key nutrient in optimising muscle hypertrophy. Protein supports strength gain and improves body composition by maintaining muscle mass and decreasing fat mass during hypocaloric energy intake (Garthe et al. 2011; Witard et al. 2016). Hence, protein quantity, quality, time, distribution and frequency in support of muscle hypertrophy, strength gain and fat mass loss are discussed in this section, according to the scientific evidence.

#### 4.7.2.1. Protein Quantity, Time, Distribution and Frequency

The American Institute of Medicine recommends a minimum protein intake between 0.8 and 0.9 g·kg\(^{-1}\) of body mass per day for adults. This recommendation is considered to be adequate for ~98% of the healthy population, aged above 19 years (Institute of Medicine 2005a). This Recommended Dietary Allowance (RDA) for protein does not differ for individuals involved in RT or sedentary populations but should meet the minimum requirements for people with moderate physical activity (Layman 2009). In a joint position statement, Rodriguez et al. (2009) provided different recommendations for daily protein intake for individuals involved in strength and/or endurance training, i.e. 1.2–1.7 g·kg\(^{-1}\)·d\(^{-1}\). More recently, Thomas et al. (2016) provided updated daily protein intake guidelines of 1.2–2.0 g·kg\(^{-1}\)·d\(^{-1}\) for athletes, in support of metabolic adaptation, remodelling and repair. There is no evidence to suggest that higher than 2.2 g·kg\(^{-1}\)·d\(^{-1}\) of protein intake would have an additional positive effect on adaptation to RT (Morton et al. 2018). However, protein intake, i.e. 1.6–2.2 g·kg\(^{-1}\)·d\(^{-1}\) or even up to 2.4 g·kg\(^{-1}\)·d\(^{-1}\) was proposed for promoting lean mass gain with concurrent body fat loss (Garthe et al. 2011; Hector and Phillips 2018; Maughan et al. 2018; Witard et al. 2019).

Several studies have demonstrated that mTOR and MPS responses depend on the protein quantity per single EO (Moore et al. 2009a; Moore et al. 2012; Witard et al. 2019).
A 20 to 40 g dose or 0.25–0.3 to 0.5 g·kg\(^{-1}\) of protein per feeding has been suggested to maximally activate the previously described mechanism responsible for optimum adaptation (Res et al. 2012; Witard et al. 2014; Macnaughton et al. 2016; Thomas et al. 2016; Maughan et al. 2018; Moore 2019). However, the recommended protein intake from the upper range was derived from research involving whole-body RT performed by resistance-trained young men (Macnaughton et al. 2016). A recent meta-analysis suggests that 0.3 g·kg\(^{-1}\) of rapidly digested and high-quality protein should be considered as optimal post-RT nutrient support for maximising MPS (Moore 2019). Since this recommendation is based on isolated, high-quality protein sources (e.g. whey protein supplementation), the recommendations for protein intake per dose with food is hypothesised to be closer to 0.4–0.5 g·kg\(^{-1}\) (Witard et al. 2019). This altered protein dose relates to protein sources of different quality or concurrent intakes of other ingredients that may alter protein digestibility (see Table 8 and Table 9). Furthermore, evidence suggests that individuals benefit from post-RT, pre-sleep, slowly digested protein feeding, which provides 40 g (~0.5 g·kg\(^{-1}\)) of protein (Res et al. 2012; Trommelen and van Loon 2016). Conversely, the provision of 30 g of protein pre-sleep (~0.4 g·kg\(^{-1}\)) is not optimal to maximise post-exercise rates of MPS overnight (Trommelen et al. 2018). To summarise, according to the scientific evidence, for the dietary assessment in this research project the author accepts 0.3–0.5 g·kg\(^{-1}\)·EO\(^{-1}\) as an optimal quantity of protein consumed throughout the day to maximise MPS (Macnaughton et al. 2016; Maughan et al. 2018; Moore 2019). Moreover, at least 0.5 g·kg\(^{-1}\)·EO\(^{-1}\) is considered an optimal protein intake within an hour pre-sleep to further stimulate MPS overnight (Res et al. 2012; Trommelen and van Loon 2016).

Amino acids have the potential to raise the concentration of circulating insulin. In the post-absorptive state and the non-exercise model, ingestion of a single bolus of whey protein [48 g, an equivalent of 20 g of essential amino acids (EAA)] increases insulin concentration sharply, within 30 to 60 minutes. Insulin returns to baseline values within 90 minutes after the protein feeding (Atherton et al. 2010). The sarcoplasmic and myofibrillar fractional synthetic rates peak between 46 and 90 minutes and return to baseline within three hours after protein feeding (Atherton et al. 2010). Similar to myofibrillar fractional synthetic rate, the concentrations of non-essential amino acids (NEAA) in plasma are no different from postabsorptive values at three hours following
protein intake. Plasma EAA levels return to pre-ingestion values within four hours of protein intake. The plasma leucine concentrations remain elevated up to four hours, and the intramuscular level of leucine return to baseline after three hours of protein ingestion. (Atherton et al. 2010) The MPS does not respond to amino acid stimulation after three hours, even when leucine and other EAA are still available in circulation above post-absorptive values (Rennie et al. 2004; Atherton et al. 2010). These data suggest that ingestion of one single bolus of protein in the post-absorptive state is sufficient to maximally stimulate MPS at rest. Moreover, an additional quantity of protein intake within three hours to what is considered as “optimal”, does not stimulate MPS further (Atherton et al. 2010).

Resistance training stimulus prolongs the activation of mTOR for at least 24 hours post-training (Chesley et al. 1992; MacDougall et al. 1995; Tipton et al. 2003; Cuthbertson et al. 2006; Burd et al. 2011; Atherton and Smith 2012). Therefore, the prolonged MPS response to protein intake post-RT (Burd et al. 2009; Moore et al. 2009b; Atherton et al. 2010) allows for optimisation of dietary patterns within 24 hours post-exercise. Nonetheless, there is a difference in time of RT-induced MPS in trained versus untrained individuals. Evidence suggests that the rise in MPS can continue up to 48 hours in untrained subjects compared to trained individuals, where an increase in MPS is observed for at least 24 hours (Burd et al. 2011). It has been shown that the overall MPS response within 12 hours or 24 hours depends on the apportioning of the recommended daily quantity of protein (Moore et al. 2012; Areta et al. 2013; Mamerow et al. 2014). There is a common trend in protein ingestion post-RT, and most of the studies cited in this chapter investigated the post-exercise effect of protein intake on MPS. However, it has been shown that there is no difference in MPS response with immediate protein intake either pre- or post-RT (Tipton et al. 2007; Schoenfeld et al. 2017). One long-term study has shown that there is no significant difference in the gain of lean tissue mass following protein intake either pre- or post-RT (Schoenfeld et al. 2017). Moreover, in Volek et al. (2013), protein intake during RT over nine months increases lean tissue mass in untrained subjects, for whom daily protein intake is above the RDA (~1.4 g·kg\(^{-1}·d\)\(^{-1}\)). Nevertheless, long-term studies suggest that initial protein intake post-RT should occur immediately or within the first hours after RT, which results in a greater increase in muscle mass (Hartman et al. 2007; Burd et al. 2009; Phillips 2012).
Three evenly distributed feedings consisting of high quality and optimal quantity of protein, result in superior MPS than protein apportioning skewed towards dinner, in young untrained men on their non-exercise day (Mamerow et al. 2014). Even protein distribution every three hours induces greater overall MPS following RT than the same protein intake consumed on two occasions (every six hours) or eight occasions (every 1.5 hours) by resistance-trained males (Areta et al. 2013). These findings mirror daily recommended 3–4 EO consumed every 3–5 hours after RT to stimulate maximal exercise-induced rates of MPS (Moore et al. 2012; Thomas et al. 2016; Maughan et al. 2018). It seems that the daily recommendation of 3–4 EO intake every 3–5 hours assumes or favours an RT session performed in the morning hours to give opportunities to satisfy recommended intake within the waking hours.

Timing and distribution of protein ingestion in proximity to RT are of importance in the PEN approach. As such, the nutritional strategy should be reviewed up to 24 hours post-exercise (Churchward-Venne et al. 2012b) within waking hours in resistance-trained individuals. Considering that sleep time occurs for 6–8 hours within 24 hours post-RT, there are still 16 to 18 hours within which protein intake could be optimised. The recommended 3–5 hour protein distribution within this paradigm is more relevant than the recommended frequency of EO. For example, if protein were consumed every three hours, it would give 5–6 EO post-RT. However, if the three-hour distribution pattern was adopted and the pre-RT feeding was consumed within one hour pre-RT, and the RT session lasted one hour, the next protein-optimised EO could be consumed within two hours post-RT. This example shows that pre-RT feeding is a viable opportunity within the proposed distribution pattern in the PEN approach. However, the consumption of additional bolus or small quantities of protein during exercise does not seem to be beneficial if either pre-RT or post-RT protein intake occurs within an hour of an RT session.

According to the presented mechanism of muscle hypertrophy (see Section 4.4.), the increase in muscle cross-sectional area supports strength gain. Hence, the dietary requirements in support of muscle hypertrophy will concurrently support strength gain. Protein supplementation for muscular strength gain was discussed by Morton et al. (2018). The results indicated that 1RM increased in the presence of protein supplementation [1.5 g·kg⁻¹·d⁻¹ of whey protein (Cribb et al. 2007) or 50 g·d⁻¹ of pea or whey protein (Babault et al. 2015)] and an RT programme of 11–12 weeks. The
strength gain of 1RM increased by 27% \([M (SD) 27 (22) \text{ kg}]\). In a review of research (Morton et al. 2018), protein supplementation alone resulted in strength gain of 9% \((2.49 \text{ kg})\) in studies of at least six weeks duration. The protein intake supplement was added into participants’ daily protein intake in 1–4 daily doses. On average, \([M (SD)]\) 42 (32) g of additional protein was supplemented by young participants in the form of whey, soy or pea protein, milk, chocolate milk or beef, or a composition of whey with casein or amino acids. The protein doses were spread equally throughout a day or consumed either pre- or post-RT session. No time-dependent response on strength gain was observed (Morton et al. 2018).

Hoffman et al. (2009) conveyed that timing of protein intake (\(~0.42 \text{ g·kg}^{-1}\) of blended collagen protein isolate, whey and casein protein isolate that contained 3.6 g of leucine) pre- and post-RT did not affect strength gain, body mass or percentage of fat mass in comparison to the same dose of protein intake in the morning and the evening over 10 weeks. However, gain in strength was observed for all groups in 1RM squat. Participants of the research study consumed \([M (SD)] 1.4 (0.2)–2.3 (0.8) \text{ g·kg}^{-1}·\text{d}^{-1}\) of protein within the 10 weeks of research study duration. According to the authors, no further strength gain was observed because of the suboptimal energy intake by the resistance-trained participants \([29 (9.7) \text{ kcal·kg}^{-1}·\text{d}^{-1}]\), instead of recommended 44–50 kcal·kg·d⁻¹] (Hoffman et al. 2009).

In another study, untrained subjects were engaged in RT four times a week for eight weeks (Rozenek et al. 2002). Participants were allocated into three groups. Participants in the first and second group consumed the additional \(~2000 \text{ kcal·d}^{-1}\) that provided carbohydrate and either of 1.6 (0.3) g·kg⁻¹·d⁻¹ or 0.3 (0.1) g·kg⁻¹·d⁻¹ of protein to their habitual energy and macronutrient intakes. Participants in the third group were a control group and did not receive any supplements. Hence, daily energy intake in the control group was significantly lower than in the two other groups. Nevertheless, strength gain was observed in all three groups but no significant difference in strength gain was shown between the three groups. The same study demonstrated that body mass increased in the supplemented diet groups but not in the control group. The significant increase in lean tissue mass was observed in all groups, significantly higher in groups that consumed an additional amount of protein and carbohydrate than in the control group. No significant difference was observed between both intervention groups. Significantly lower fat mass and percent body fat was observed only in the
control group (-1.3 kg) pre- and post-test conditions. However, there was no significant difference in fat mass and percent body fat loss between groups (Rozenek et al. 2002). Both studies have shown that when at least 1.3–1.4 g·kg⁻¹·d⁻¹ of protein is consumed daily, neither additional consumption of protein nor its distribution improves further strength gain. This evidence suggests that daily optimal protein and carbohydrate intake rather than their consumption in proximity to an RT session supports strength gain in untrained and resistance-trained individuals (Rozenek et al. 2002; Hoffman et al. 2009).

Daily protein intake and protein intake post-RT have been shown to increase fat mass loss and support maintenance of lean tissue mass. Supplementation with 20 g of protein (135 g of tinned lean beef) post-RT was shown to significantly decrease fat mass [difference $M (SD)$ -1.9 (2.9) kg] but not lean tissue mass in comparison to a control group. The training programme lasted for eight weeks. Daily energy and macronutrient intakes of healthy young participants were not reported (Negro et al. 2014). Protein intake immediately post-RT and again an hour post-RT compared to carbohydrate (2 x 500 ml of fat-free milk or isoenergetic carbohydrate) over 12 weeks showed significantly greater lean tissue mass gain and body mass loss in the protein group than in the carbohydrate group of young healthy women. Of reported nutrients, the only significant differences in daily intakes were protein intake (~20 g) and calcium intake (~530 mg) during a 12-week RT programme (Josse et al. 2010). In a study by Hulmi et al. (2016) 30 g (~0.4 g·kg⁻¹) of protein intake post-RT resulted in greater fat loss (difference was ~1.5 kg of fat mass) than in an isocaloric energy equivalent supplement post-exercise in resistance-trained females. There was no difference in daily energy intake between groups. The FFM significantly increased in a protein group, when protein intake was expressed relative to participants’ body mass. Lastly, Hector and Phillips (2018) hypothesised that daily protein requirements increase with the higher daily energy deficit (e.g. ~1.4 g·kg⁻¹·d⁻¹ of protein could be recommended with a daily energy deficit of approximately 10% or ~2.0 g·kg⁻¹·d⁻¹ when the energy deficit was about 25%).

To sum up, protein in combination with exercise has a superior effect on body fat loss and preservation of lean body mass than carbohydrate and exercise. It is worth considering that high-protein and low-carbohydrate diets promote greater weight loss than low-fat diets. The greater weight loss might be a result of increased satiety after
protein intake than either carbohydrate or fat (Schoeller and Buchholz 2005). Lastly, protein intake should be proportional to one’s body mass, not energy intake (Layman 2009), to support an individual’s aim and anabolic environment.

Based on the discussed studies, optimised protein intake patterns in proximity to RT improves muscle hypertrophy, maintenance of muscle mass and greater fat loss in hypocaloric conditions. Sufficient daily protein intake is required to support strength gain in the presence of RT, rather than a pattern of protein intake in proximity to RT. In discussed studies, researchers focused on protein intake using high-quality protein sources, such as whey protein. In some scenarios casein or amino acids were added to a whey protein. Less attention was given in research to food sources of protein and their effect on muscle hypertrophy, strength gain or fat loss. Moreover, in most of the discussed research studies in this section, the protein source of higher digestibility was examined, e.g. whey over casein protein, milk over yoghurt or tinned beef over fried steak. Therefore, more consideration of protein quality is given below.

4.7.2.2. Protein Quality and Digestibility

It is suggested that a high-quality source of protein providing between ~8.5 g (post resistance exercise) and 10 g (at rest) of EAA maximally stimulates MPS (Moore et al. 2009a). Evidence suggests that of all EAA, the most potent in promoting MPS is leucine (Witard et al. 2016). Approximately three grams of leucine occurs naturally in a dose of 20–25 g of high-quality protein (e.g. whey protein). A single dose of 20–25 g of whey protein is considered to provide the optimal quantity of EAA to maximally support exercise-induced MPS (Churchward-Venne et al. 2012a; Churchward-Venne et al. 2012b). Researchers demonstrated that in the initial post-resistance exercise phase (0–4.5 hours) a suboptimal dose of protein (6.25 g of whey protein) with leucine (5 g) induced a similar effect to 25 g of whey protein (~3 g of leucine) on MPS (Churchward-Venne et al. 2014). However, leucine alone, despite its high-potency, does not stimulate MPS to the same extent as a full profile of EAA (Witard et al. 2016).

The source of protein determines its digestibility and bioavailability. Wilkinson et al. (2007) and Hartman et al. (2007) compared fat-free milk to isonitrogenous and isoenergetic soy protein beverage, consumed after RT. They have shown that whey protein is superior in stimulating MPS than casein and other plant-based protein sources. The rationale behind these findings is that plant-based protein sources have lower digestibility (45–80% compared to animal protein > 90%) according to the
Digestible Indispensable Amino Acid Score, contain less leucine than animal protein and are converted more quickly into urea (most likely due to the unbalanced amino acids profile). This imbalance potentially could be corrected by consuming higher quantities of plant protein or by fortifying these products to improve the amino acid profile of food, especially the leucine content (van Vliet et al. 2015). There is mounting evidence that the consumption of whole foods (i.e. whole eggs) results in higher MPS than the intake of protein-rich components of this food matrix (i.e. egg white) post-RT in young, resistance-trained men (van Vliet et al. 2017). Since to date the effect of protein intake supportive of RT adaptation was primarily investigated using protein dietary supplements, more research is needed to examine the effect of whole food matrixes, where different nutrients and anti-nutritional factors may be co-ingested. Thus, Table 8 presents food and dietary supplement sources of protein divided into four categories that consider protein quality (low, high) and digestibility (low, high). Additionally, Table 9 summarises factors that influence protein digestibility in food products.

Table 8 Examples of quality and digestibility of food-derived protein sources

<table>
<thead>
<tr>
<th>Higher Digestibility</th>
<th>Lower Digestibility</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Quality</strong></td>
<td><strong>Low Digestibility</strong></td>
</tr>
<tr>
<td>Meat, poultry, fish, eggs, isolated soy protein, milk</td>
<td>Casein powder, cheese and yoghurt</td>
</tr>
<tr>
<td>(Phillips et al. 2015).</td>
<td>(Phillips et al. 2015).</td>
</tr>
<tr>
<td><strong>Low Quality</strong></td>
<td><strong>Plant-based sources: maize, oat, bean, pea, and potato (45–80% digestibility)</strong></td>
</tr>
<tr>
<td>Isolated pea protein concentrate and wheat gluten</td>
<td>(Food and Agriculture Organization of the United Nations 2011; van Vliet et al. 2015);</td>
</tr>
<tr>
<td>(digestibility similar to that of animal-based protein</td>
<td>Legumes, grains, nuts, seeds, and vegetables due to naturally occurring</td>
</tr>
<tr>
<td>sources) (van Vliet et al. 2015).</td>
<td>anti-nutritional factors (e.g. tannins, phytates, trypsin inhibitors,</td>
</tr>
<tr>
<td></td>
<td>glucosinolates, isothiocyanates) in plant-based sources (Food and</td>
</tr>
<tr>
<td></td>
<td>Agriculture Organization of the United Nations 2011).</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9 Factors influencing protein digestibility

<table>
<thead>
<tr>
<th>Increase Digestibility</th>
<th>Decrease Digestibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting, mincing, masticating solid food (e.g. beef) (Gorissen et al. 2015);</td>
<td>Solid as opposite to liquid food matrices (Burke et al. 2012b);</td>
</tr>
<tr>
<td>Cooking temperature at 75 degrees Celsius (Bax et al. 2013);</td>
<td>Cooking below or above 75 degrees Celsius (Bax et al. 2013);</td>
</tr>
<tr>
<td>Fat content of minced beef may increase its digestibility in comparison to skimmed milk (Burd et al. 2015).</td>
<td>Co-ingestion of fibre and anti-nutritional factors (e.g. tannins, phytates, trypsin inhibitors, glucosinolates, isothiocyanates), which may be naturally occurring in plant-based sources (Food and Agriculture Organization of the United Nations 2011; Sarwar Gilani et al. 2012);</td>
</tr>
<tr>
<td></td>
<td>Fat in eggs decreases digestibility but improves muscle protein synthesis (van Vliet 2015);</td>
</tr>
<tr>
<td></td>
<td>Carbohydrate co-ingestion decreases protein digestibility (Gorissen et al. 2014) but improves muscle protein balance when a suboptimal quantity of protein is consumed (Staples et al. 2011).</td>
</tr>
</tbody>
</table>

### 4.7.3. Carbohydrate Co-Ingestion

Sufficient carbohydrate intake reduces protein oxidation for energy substrate, improving protein balance (Simmons et al. 2016). High-protein, low-carbohydrate diets improve body composition but may decrease performance or negatively influence a training programme if the provision of energy is not sufficient. Thus, carbohydrate is a vital macronutrient in the replenishment of glycogen stores post-exercise within the recovery phase (Simmons et al. 2016). However, in the post-resistance exercise state, the co-ingestion of carbohydrate with protein does not extend the positive effect on MPS more than a dose of high-quality protein alone (Glynn et al. 2010; Staples et al. 2011). This effect suggests that the MPS process is caloric independent (Borsheim et al. 2002). Additionally, insulin levels after co-ingestion of protein and carbohydrate do not have an additive effect on muscle protein breakdown (MPB), as compared to the effect of insulin when a single, optimal dose of protein (25 g of whey protein) is
consumed. Furthermore, co-ingestion of carbohydrate and protein does not inhibit the positive effect of protein feeding and resistance exercise on MPS (Staples et al. 2011). Hence, carbohydrate can be consumed independently of protein in the pre- and post-exercise states to maximise MPS and suppress MPB if optimum high-quality protein is consumed (i.e. 25 g of whey protein). The 25 g of whey protein consumed post-RT, increases insulin to ~15–20 μIU·ml⁻¹ in the first ~20–60 minutes post-ingestion (Staples et al. 2011). There is no further increase in MPS or suppression in MPB above this level of insulin when additional carbohydrate is provided (Miller et al. 2003; Staples et al. 2011). However, in the scenario of suboptimal protein intake and low insulin levels, i.e. 5 μU·ml⁻¹, a co-ingestion of carbohydrate can enhance the net protein balance by ~30% by suppressing MPB (Glynn et al. 2010; Staples et al. 2011). It is worth noting that even a small dose of whey protein (10 g) consumed with carbohydrate (fructose, 21 g) increases the insulin level to ~25 μIU·ml⁻¹ (Tang et al. 2007), suggesting this dose of protein and carbohydrate to be a sufficient amount to suppress MPB. However, Tang et al. (2007) did not measure MPB response to the protein and carbohydrate feeding in their research study. Nevertheless, in the absence of protein, 100 g of carbohydrate reduces MPB ~30% in comparison to the ingestion of flavoured water post-RT (Borsheim et al. 2004).

Daily carbohydrate intake may be manipulated to achieve energy targets to support training adaptation and sports performance or to trigger energy deficit during dieting (Thomas et al. 2016). An RT session may deplete glycogen stores by 24–40% (Slater and Phillips 2011). Hence, optimal daily carbohydrate intake allows for sustaining the duration and intensity of a training session or a competition event. However, the importance of carbohydrate intake in proximity to RT in support of strength gain, in addition to optimal daily intake, has not been determined (Slater and Phillips 2011). Moreover, in low-energy diets, the consumption of protein rather than carbohydrate allows for preserving lean tissue mass, greater body mass and fat mass loss (Layman et al. 2005).

The assessment of carbohydrate quantity per EO peri-RT is considered within the PEN approach when protein intake is below the recommended amount per EO (i.e. < 0.3 g·kg⁻¹·EO⁻¹). Therefore, carbohydrate consumption with food may improve muscle protein balance. Moreover, carbohydrate intake promotes post-exercise glycogen replenishment and, together with high-quality sources of fat, secures optimal
physiological functions and EA, in line with daily general guidelines (Loucks et al. 2011; Thomas et al. 2016).

4.7.4. Fat
The general recommendation for fat intake among general and athletic populations is above 20% of daily energy intake long-term. The higher range fluctuates around 35% of total daily energy intake (Manore 2005; Thomas et al. 2016). There are concerns that excess fat intake may compromise carbohydrate intake or cause excess of TEI and, in consequence, to increase fat mass (Burke et al. 2004; Rawson et al. 2013). When the goal is to decrease fat mass, one dietary strategy is to provide 25–30% of TEI from fat, which lies within general fat intake recommendations and it is favoured over very low fat intake (i.e. 10–20% of TEI from fat) (Aragon et al. 2017). Fat intake above 20% of TEI supports adequate consumption of monounsaturated and polyunsaturated fatty acids. Among fatty acids, the supplementation of n-3 polyunsaturated fatty acids has been studied as an anabolic stimulus (Smith et al. 2011). The eight-week, daily supplementation of four grams of n-3 polyunsaturated fatty acids in healthy young and middle-aged adults improved anabolic response to hyperinsulinemia and hyperaminoacidaemia (Smith et al. 2011). McGlory et al. (2016) showed that eight-week supplementation of five grams of n-3 polyunsaturated fatty acids, followed by a RT session and ingestion of 30 g of whey protein post-RT by resistance-trained individuals did not improve MPS. Thus, n-3 polyunsaturated fatty acids do not support muscle growth during RT or diminish the loss of muscle mass during dieting (Philpott et al. 2019). Current guidelines recommend consumption of n-3 polyunsaturated fatty acids from rich food sources rather than supplementation (Maughan et al. 2018).

4.7.5. Microelements
Vitamins and microelements are responsible for many metabolic processes. Some vitamins may provide essential health benefits. Meanwhile, others may have an ergogenic effect to reduce the oxidative damage (i.e. Vitamin C, E) or to support the immune system during high-intensity training (i.e. Vitamin C, Zinc). Moreover, adequate daily intake of microelements like calcium, magnesium, potassium and sodium is imperative for the maintenance of normal muscle function (Turck et al. 2018). The Dietary Reference Intake (DRI) values (Institute of Medicine 2000a; 2011) for fibre, vitamins and microelements according to RDA or Adequate Intake (AI) values (Institute of Medicine 2000a; 2011) are presented in Table 10. Volpe (2007)
discussed that micronutrients supplementation would not provide an additive effect on health and performance in well-nourished athletes whose intake of energy and macronutrients is adequate. However, if the DRI for micronutrients are not met due to the consumption of poor nutrient density of EO, processed food, and unbalanced low-energy diets, a positive effect on the health of micronutrients supplementation may be observed (Kreider et al. 2010). In conclusion, there is no evidence that supplementation of other microelements in the presence of RT may support training adaptation, body mass or fat loss.

Table 10 Reference values for daily nutrient intakes

<table>
<thead>
<tr>
<th>Type of nutrient</th>
<th>Recommended daily intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre (AOAC) (g·day⁻¹)</td>
<td>38.0¹</td>
</tr>
<tr>
<td>Omega-3 fatty acids (g·day⁻¹)</td>
<td>-</td>
</tr>
<tr>
<td>Cholesterol (mg·day⁻¹)</td>
<td>-</td>
</tr>
<tr>
<td>Sodium (mg·day⁻¹)</td>
<td>1500¹</td>
</tr>
<tr>
<td>Potassium (mg·day⁻¹)</td>
<td>4700¹</td>
</tr>
<tr>
<td>Calcium (mg·day⁻¹)</td>
<td>1000</td>
</tr>
<tr>
<td>Magnesium (mg·day⁻¹)</td>
<td>400–420</td>
</tr>
<tr>
<td>Phosphorus (mg·day⁻¹)</td>
<td>700</td>
</tr>
<tr>
<td>Iron (mg·day⁻¹)</td>
<td>8</td>
</tr>
<tr>
<td>Copper (mg·day⁻¹)</td>
<td>0.9</td>
</tr>
<tr>
<td>Zinc (mg·day⁻¹)</td>
<td>11</td>
</tr>
<tr>
<td>Chloride (mg·day⁻¹)</td>
<td>2300¹</td>
</tr>
<tr>
<td>Manganese (mg·day⁻¹)</td>
<td>2.3¹</td>
</tr>
<tr>
<td>Selenium (µg·day⁻¹)</td>
<td>55</td>
</tr>
<tr>
<td>Iodine (µg·day⁻¹)</td>
<td>150</td>
</tr>
<tr>
<td>Vitamin A (µg·day⁻¹)²</td>
<td>900</td>
</tr>
<tr>
<td>Vitamin D (µg·day⁻¹)</td>
<td>15</td>
</tr>
<tr>
<td>Vitamin E (mg·day⁻¹)</td>
<td>15</td>
</tr>
<tr>
<td>Vitamin K₁ (µg·day⁻¹)</td>
<td>120¹</td>
</tr>
<tr>
<td>Vitamin B₁ (mg·day⁻¹)</td>
<td>1.2</td>
</tr>
<tr>
<td>Vitamin B₂ (mg·day⁻¹)</td>
<td>1.3</td>
</tr>
<tr>
<td>Niacin (mg·day⁻¹)</td>
<td>16</td>
</tr>
<tr>
<td>Pantothenic acid (mg·day⁻¹)</td>
<td>5¹</td>
</tr>
</tbody>
</table>
### Type of nutrient | Recommended daily intake
---|---
Vitamin B₆ (mg·day⁻¹) | 1.3
Biotin (µg·day⁻¹) | 30¹
Folates (µg·day⁻¹) | 400
Vitamin B₁₂ (µg·day⁻¹) | 2.4
Vitamin C (mg·day⁻¹) | 90

Note. Data are Recommended Dietary Allowances (RDA) values Institute of Medicine (2000a; 2011). When no RDA exist, data are presented as Adequate Intake (AI) values; ¹Adequate Intakes values; ²Retinol equivalent. AOAC–American Association of Analytical Chemists.

#### 4.7.6. Dietary Supplements

##### 4.7.6.1. Branched-Chain Amino Acids, Leucine and β-hydroxy-β-methylbutyrate

To date, there is no evidence that supplementation of leucine metabolite, i.e. β-hydroxy-β-methylbutyrate (HMB) improves muscle strength in trained individuals (Rowlands and Thomson 2009). The supplementation of 2.4 g of pure HMB stimulated myofibrillar MPS in healthy young individuals after an overnight fast at rest. Interestingly, HMB decreased MPB without increasing insulin levels (Wilkinson et al. 2013). Nonetheless, the mechanism of HMB action on MPB remains unknown. Authors concluded that consumption of either HMB or leucine (2–3 g) increases MPS from baseline after an overnight fast at rest, to levels comparable to a mixed meal (Wilkinson et al. 2013). Moreover, it has not been determined whether a similar effect would be observed peri-RT in trained individuals when HMB was added to suboptimal protein intake within a single EO. Neither branched-chain amino acids, leucine or HMB are recommended for fat mass loss due to scarce scientific evidence of their effectiveness (Hector and Phillips 2018).

##### 4.7.6.2. Creatine Monohydrate

Supplementation with creatine monohydrate facilitates RT at higher intensities, which leads to increasing the performance outcome of an RT session, i.e. greater lean mass and strength gains (Volek and Rawson 2004; Buford et al. 2007; European Food Safety Authority 2016; Maughan et al. 2018). A protocol of creatine supplementation involves daily intake of 20 g for 5–7 days or 3 grams daily for 28 days to enhance the creatine stores by ~20% (Hultman et al. 1996). Furthermore, the enhanced muscle
store of creatine can be maintained if two grams of creatine is consumed daily for the 28 days that follow (Hultman et al. 1996). Moreover, co-ingestion of carbohydrate (~100 g) or protein and carbohydrate (~50 g of each) may improve the muscular uptake of creatine (Steenge et al. 2000). In a meta-analysis, Lanheres et al. (2017) showed that creatine supplementation increases individuals’ upper-body strength for chest press and bench press. Branch (2003) indicated in a meta-analysis that on average, creatine supplementation increased 1RM by 11.2% and number of repetitions by 45.4% in exercises lasting less than 30 seconds. In comparison to the placebo group, 1RM was greater by 5.6% and number of repetitions by 22.5% after the period of supplementation. Finally, creatine supplementation was shown to have a positive effect on lean tissue mass and body mass. The magnitude of changes following supplementation was presented to be 2.2 (0.7)% for lean tissue mass and 1.2 (0.3)% for body mass (Branch 2003). Additionally, Branch (2003) showed that creatine supplementation does not change the level of body fat mass.

4.7.6.3. Caffeine
The mechanism by which caffeine may affect muscular strength is not resolved. Researchers propose either a direct effect on muscle or via the central nervous system (Warren et al. 2010). An improvement in maximum strength was observed in trained men after 5 mg·kg⁻¹ of caffeine intake 60 minutes before RT performed to failure (Duncan and Oxford 2011). Other researchers also observed significantly greater weight lifted (Woolf et al. 2008) in competitive athletes and number of repetitions to failure in trained (Duncan et al. 2013) and untrained subjects (Green et al. 2007) post-caffeine intake. However, the results are not conclusive since there are research studies that do not show the beneficial effect of caffeine ingestion before RT on muscle strength (Astorino et al. 2008; Beck et al. 2008). In a meta-analysis, caffeine intake pre-RT had a significant effect on muscular strength in trained individuals. However, a subgroup analysis revealed that caffeine intake improved upper but not lower body strength. The caffeine intake varied from 0.9–7 mg·kg⁻¹, with a majority of studies in which at least 5 mg·kg⁻¹ of caffeine was administrated among trained and untrained individuals 60 minutes before RT (Grgic et al. 2018). Further research is required to clarify these findings. However, caffeine supplementation could be considered in practical settings on a case study basis, in support of strength gain in some individuals.
4.8. Conclusions
Daily requirements of energy and nutrient intakes from food, beverages or dietary supplements have become common considerations in traditional dietary assessment and prescription. There is mounting evidence in support of time-independent and dependent nutrient intake requirements, specific to the type of exercise sessions and individuals’ goals. Besides the dietary considerations of protein, carbohydrate and the dietary supplement intakes per EO and in proximity to RT, further studies are required. Protein and carbohydrate are shown to be the most researched nutrients associated with RT and discussed goals (i.e. training adaptation and fat mass loss). However, to date, the majority of studies investigated the effect of dietary supplement intake rather than food products, on the adaptive outcome of RT. Nevertheless, dietary intake is based on co-ingestion of multiple nutrients, not intake of a single-nutrient dietary supplement. Therefore, further research should investigate optimal nutrient doses including their sources, nutrient co-ingestion or a matrix of consumed food on the targeted aims.

In summary, a dietary prescription in support of adaptation to resistance training (muscle hypertrophy and strength gain), fat loss and maintenance of muscle mass is summarised in Table 11 and Table 12. The dietary requirements to be considered during traditional dietary assessment and prescription are presented in Table 11. The evidence that supports the use of PEN prescription and assessment is provided in Table 12. Moreover, the examples of dietary prescription in presence of multiple goals are offered in Table 13. Finally, it should be noted that in the presence of other aims or the occurrence of another training session, dietary recommendations should be revised according to one’s goals and the feasibility of applying dietary recommendations.
Table 11 Evidence-based, daily dietary considerations in support of muscle hypertrophy, strength gain and fat mass loss aims, in presence of RT for young, resistance-trained individuals

<table>
<thead>
<tr>
<th></th>
<th>Muscle hypertrophy</th>
<th>Strength gain</th>
<th>Fat mass loss, muscle mass maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy (kcal·kg⁻¹ FFM·d⁻¹)</strong></td>
<td>⩾45</td>
<td>45</td>
<td>30–45</td>
</tr>
<tr>
<td><strong>Protein (g·kg⁻¹·d⁻¹)</strong></td>
<td>1.6–2.2</td>
<td>1.3–2.0</td>
<td>1.6–2.4</td>
</tr>
<tr>
<td><strong>Carbohydrate (g·kg⁻¹·d⁻¹)</strong></td>
<td>Low intensity activities: 3–5 Moderate exercise program (e.g. ~1 h·d⁻¹): 5–7</td>
<td>Low intensity activities: 3–5 Moderate exercise program (e.g. ~1 h·d⁻¹): 5–7</td>
<td>According to energy requirements</td>
</tr>
<tr>
<td><strong>Fat (%·d⁻¹ of TEI)</strong></td>
<td>20–35</td>
<td>20–35</td>
<td>25–30</td>
</tr>
<tr>
<td><strong>Other considerations:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micronutrients</td>
<td>See Table 10</td>
<td>See Table 10</td>
<td>See Table 10</td>
</tr>
<tr>
<td>Creatine (g·d⁻¹)</td>
<td>5–7 days: 20 or daily intake for 28 days: 3</td>
<td>5–7 days: 20 or daily intake for 28 days: 3</td>
<td>–</td>
</tr>
<tr>
<td>References</td>
<td>Hultman et al. (1996); Institute of Medicine (2000a; 2011); Loucks et al. (2011); Thomas et al. (2016)</td>
<td>Hultman et al. (1996); Institute of Medicine (2000a); Hoffman et al. (2009); Institute of Medicine (2011); Loucks et al. (2011); Thomas et al. (2016)</td>
<td>Institute of Medicine (2000a; 2011); Loucks et al. (2011); Thomas et al. (2016); Aragon et al. (2017); Hector and Phillips (2018); Maughan et al. (2018)</td>
</tr>
</tbody>
</table>

Note. ¹To optimise MPS, it is recommended to optimise the protein intake pattern in addition to meeting the requirements of daily protein intake, i.e. 0.3–0.5 g·kg⁻¹·EO⁻¹ of high-quality protein consumed in 3–4 EO daily and distributed every 3–5 hours (Thomas et al. 2016; Maughan et al. 2018). Moreover, if protein intake is suboptimal, co-ingestion of carbohydrate was shown to improve net muscle protein balance. ²Example of general carbohydrate recommendations that are based on duration and intensity of an exercise session. Carbohydrate intake should be tailored according to energy requirements and exercise energy expenditure to support physiological functions and sports performance (Loucks et al. 2011; Thomas et al. 2016). EA–Energy availability; EO–Eating occasion; FFM–Fat-free mass; MPS–Muscle protein synthesis; RT–Resistance training; TEI–Total energy intake.
Table 12 Evidence-based PEN prescription in support of RT-induced muscle hypertrophy and fat mass loss for young, resistance-trained individuals

<table>
<thead>
<tr>
<th>Protein</th>
<th>Muscle hypertrophy</th>
<th>Fat mass loss, muscle mass maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose (g·kg⁻¹·EO⁻¹)</strong></td>
<td>0.3–0.5 (pre-sleep ≥ 0.5)</td>
<td>0.3–0.4</td>
</tr>
<tr>
<td>(g·kg⁻¹·24h⁻¹ post-RT)</td>
<td>1.6–2.2</td>
<td>–</td>
</tr>
<tr>
<td><strong>Quality: EAA (g·EO⁻¹)</strong></td>
<td>8.5–10</td>
<td>8.5–10</td>
</tr>
<tr>
<td><strong>Leucine (g·EO⁻¹)</strong></td>
<td>2–3</td>
<td>2–3</td>
</tr>
<tr>
<td><strong>Distribution and frequency</strong></td>
<td>EO consumption within 1 h pre-RT or within the first 2–3 h post-RT. EO distribution every 3–5 h up to 24 h post-RT, within waking hours and with consideration of pre-sleep feeding within 1 h pre-bedtime</td>
<td>Single EO consumed post-RT</td>
</tr>
<tr>
<td><strong>Time of assessment</strong></td>
<td>1 h pre-, during and every 3 h up to 24 h post-RT with consideration of pre-sleep feeding within 1 h pre-bedtime</td>
<td>Within 3 h post-RT</td>
</tr>
<tr>
<td><strong>Carbohydrate</strong></td>
<td>Co-ingestion with suboptimal protein intake per EO</td>
<td>–</td>
</tr>
</tbody>
</table>

**References**
- Glynn et al. (2010); Burd et al. (2011); Staples et al. (2011); Churchward-Venne et al. (2012b); Res et al. (2012); Thomas et al. (2016); Maughan (2018); Witard et al. (2019)
- Negro et al. (2014); Hulmi et al. (2016)

*Note. EAA—Essential amino acids; EO—Eating occasion; PEN—Peri-exercise nutrition; RT—Resistance training; TEI—Total energy intake.*
Table 13 An example of evidence-based dietary considerations in support of multiple aims for young, resistance-trained individuals

<table>
<thead>
<tr>
<th></th>
<th>Muscle hypertrophy and strength gain¹</th>
<th>Strength gain and fat mass loss with the maintenance of lean tissue mass¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily dietary intake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kcal·kg⁻¹ FFM)</td>
<td>≥ 45</td>
<td>30–45</td>
</tr>
<tr>
<td>Protein (g·kg⁻¹)²</td>
<td>1.6–2.2</td>
<td>1.6–2.4</td>
</tr>
<tr>
<td>Carbohydrate (g·kg⁻¹)³</td>
<td>Low intensity activities: 3–5</td>
<td>According to energy requirements</td>
</tr>
<tr>
<td></td>
<td>Moderate exercise program (e.g. ~1 h·d⁻¹): 5–7</td>
<td></td>
</tr>
<tr>
<td>Fat (% of TEI)</td>
<td>20–35</td>
<td>25–30</td>
</tr>
<tr>
<td>Other considerations:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micronutrients</td>
<td>See Table 10</td>
<td>See Table 10</td>
</tr>
<tr>
<td>Creatine (g·d⁻¹)</td>
<td>5–7 days: 20 g or</td>
<td>Creatine 5–7 days: 20 g or</td>
</tr>
<tr>
<td></td>
<td>Daily intake for 28 days: 3 g</td>
<td>Daily intake for 28 days: 3 g</td>
</tr>
<tr>
<td>PEN intake</td>
<td>Protein</td>
<td></td>
</tr>
<tr>
<td>Dose (g·kg⁻¹·EO⁻¹)</td>
<td>0.3–0.5 (pre-sleep ≥ 0.5)</td>
<td>0.3–0.4</td>
</tr>
<tr>
<td>(g·kg⁻¹·24h⁻¹ post-RT)</td>
<td>1.6–2.2</td>
<td>–</td>
</tr>
<tr>
<td>Quality: EAA (g·EO⁻¹)</td>
<td>8.5–10</td>
<td>8.5–10</td>
</tr>
<tr>
<td>Leucine (g·EO⁻¹)</td>
<td>2–3</td>
<td>2–3</td>
</tr>
<tr>
<td>Distribution and frequency</td>
<td>EO consumption within 1 h pre-RT or within the first 2–3 h post-RT. EO distribution every 3–5 h up to 24 h post-RT, within waking hours and with consideration of pre-sleep feeding within 1 h pre-bedtime</td>
<td>Single EO consumed post-RT</td>
</tr>
<tr>
<td>Time of assessment</td>
<td>Muscle hypertrophy and strength gain¹</td>
<td>Strength gain and fat mass loss with the maintenance of lean tissue mass¹</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>1 h pre-, during and every 3 h up to 24 h post-RT with consideration of pre-sleep feeding within 1 h pre-bedtime</td>
<td>Within 3 h post-RT</td>
</tr>
</tbody>
</table>

**Carbohydrate**

- Co-ingestion with suboptimal protein intake per EO

**References**

- Hultman et al. (1996); Institute of Medicine (2000a); Glynn et al. (2010); Burd et al. (2011); Institute of Medicine (2011); Loucks et al. (2011); Staples et al. (2011); Churchward-Venne et al. (2012b); Res et al. (2012); Thomas et al. (2016); Maughan (2018); Witard et al. (2019)
- Hultman et al. (1996); Institute of Medicine (2000a; 2011); Loucks et al. (2011); Areta et al. (2014); Negro et al. (2014); Hulmi et al. (2016); Thomas et al. (2016); Aragon et al. (2017); Hector and Phillips (2018); Maughan et al. (2018)

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**Note.**¹ Caffeine intake 60 minutes before RT might be considered on an individual basis in support of strength gain (Grgic et al. 2018).

² To optimise MPS it is recommended to optimise the protein intake pattern in addition to meeting the requirements of daily protein intake, i.e. 0.3–0.5 g·kg⁻¹·EO⁻¹ of high-quality protein consumed in 3–4 EO daily and distributed every 3–5 hours (Thomas et al. 2016; Maughan et al. 2018). Moreover, if protein intake is suboptimal, co-ingestion of carbohydrate was shown to improve net muscle protein balance.

³ Example of general carbohydrate recommendations that are based on duration and intensity of an exercise session. Carbohydrate intake should be tailored according to energy requirements and exercise energy expenditure to support physiological functions and sports performance (Loucks et al. 2011; Thomas et al. 2016). EA–Energy availability; EO–Eating occasion; FFM–Fat-free mass; MPS–Muscle protein synthesis; RT–Resistance training; TEI–Total energy intake.
Chapter 5
Assessment of the Dietary Intake of Resistance-Trained Individuals Using Traditional and Peri-Exercise Nutrition Methods of Analysis

A summary of traditional dietary assessment was accepted for presentation in a Free Communication session at the 2020 American College of Sports Medicine (ACSM) Annual Meeting, World Congress on Exercise is Medicine® and the World Congress on the Basic Science of Sports Medicine in San Francisco, USA. The abstract was published as Kozior, M., Jakeman, P. M., Davies, R. W., Norton, C. (2020), titled 'An investigation of dietary patterns and macronutrient intakes among resistance-trained men' in Medicine & Science in Sports & Exercise, 52(7S), 758, available: http://dx.doi.org/10.1249/01.mss.0000683444.35179.c0. (Appendix 4)

Elements of the peri-exercise nutrition data discussed in this chapter were presented in an oral communication session at the 2019 International Sport and Exercise Nutrition Conference (ISENC) in Newcastle, UK. The abstract was published as Kozior, M., Jakeman, P. M., Davies, R. W., Norton, C. (2019), titled 'Assessing adequacy of protein feeding in resistance-trained athletes; re-visited through peri-training nutrition (PTN)' in International Journal of Sport Nutrition and Exercise Metabolism, 30 (S1), S1-5, available: https://doi.org/10.1123/ijsnem.2020-0065. (Appendix 5)
5.1. List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>Adequate Intake/s</td>
</tr>
<tr>
<td>AOAC</td>
<td>American Association of Analytical Chemists</td>
</tr>
<tr>
<td>CD</td>
<td>Competition day/s</td>
</tr>
<tr>
<td>DRI</td>
<td>Dietary Reference Intake/s</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>MPS</td>
<td>Muscle protein synthesis</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RD</td>
<td>Rest day/s</td>
</tr>
<tr>
<td>RDA</td>
<td>Recommended Dietary Allowance/s</td>
</tr>
<tr>
<td>RT</td>
<td>Resistance training</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error</td>
</tr>
<tr>
<td>TD</td>
<td>Training day/s</td>
</tr>
<tr>
<td>TEI</td>
<td>Total energy intake</td>
</tr>
</tbody>
</table>

5.2. Abstract

Whether or not resistance-trained individuals meet the required nutrient intake to support adaptation to resistance training (RT), is as yet, equivocal. Protein is considered a key nutrient in support of adaptation to RT. Additionally, carbohydrate is recommended to improve net muscle protein balance, should protein provision per EO be suboptimal (Glynn et al. 2010; Staples et al. 2011; Churchward-Venne et al. 2012b). The aim of this study was to examine the patterns and adequacy of energy and nutrient intakes in resistance-trained individuals undertaking a 7-day microcycle resistance exercise programme designed to increase muscle hypertrophy and strength gain. Daily and per eating occasion (EO) energy and/or nutrient intakes of resistance-trained males were analysed by traditional dietary assessment methods and the peri-exercise nutrition (PEN) approach that was presented in Chapter 2, according to methods described in Chapter 3. According to traditional daily and per EO analysis, the recommended intake of protein (see Chapter 4) was considered as optimal for the 7-day averaged daily [1.9 (0.5) g·kg\(^{-1}·d\(^{-1}\)] and per main EO [0.5 (0.4–0.6) g·kg\(^{-1}·EO\(^{-1}\)] protein intake, and daily number of EO [5 (4–6)]. Analysis of protein intake using the PEN approach revealed that the most prominent omissions of protein intake occurred one hour pre-RT, during RT and one hour pre-bedtime. Non-optimal protein
intake per EO was reported in 44% of EO ($N = 608$) and overall distribution of EO was non-optimal in 71% of cases post-RT ($N = 402$). These data suggest that the PEN approach could supplement the traditional dietary assessment method in monitoring the desired nutrient intake in support of the trained-individuals’ exercise-specific goals.

5.3. Introduction

Trained individuals and athletes engage in varied types of exercise sessions within a sports discipline. However, there is a paucity of reporting daily and per EO dietary intake of resistance-trained individuals (MacKenzie et al. 2015; Antonio et al. 2016). Resistance training (RT) is performed as either a main component of training programmes or as a less prominent part of a diverse exercise programme within a sports discipline. The adaptive outcomes of RT, such as muscle hypertrophy and strength gain, are supported by nutrient intake. Protein is a key nutrient in RT optimised by the daily quantity and pattern of intake in support of RT adaptation (Witard et al. 2016; Maughan et al. 2018). The pattern of protein intake refers to the quantity and quality per EO, frequency, distribution and time of intake in proximity to RT sessions. The recommended daily amount and pattern of protein intake and consideration of carbohydrate co-ingestion in support of RT adaptation, when protein intake per EO is suboptimal, is described in detail in Chapter 4.

This chapter undertakes a traditional and PEN approach to the analysis of 7-day, weighed dietary intake by resistance-trained individuals participating in an investigation of nutrient support of RT adaptation (i.e. muscle hypertrophy and strength gain). The traditional dietary analysis examined daily nutrient intakes over the 7-day period, with diversification on training and rest days. The PEN analysis focused on dietary analysis in proximity to RT sessions and the nutrient support of the outcome of RT adaption. The traditional and PEN methods of dietary analysis in trained individuals and athletes are described in Chapter 2. To the author’s knowledge, this is the first study to undertake a PEN analysis of protein intake in proximity to resistance training per se, and specifically, in support of a programme of resistance training designed to improve muscle hypertrophy and strength gain in resistance-trained individuals.
5.4. Aim
This study aimed to examine the patterns and/or adequacy of energy and nutrient intakes in support of RT adaptation (i.e. muscle hypertrophy and strength gain) within a 7-day training microcycle in resistance-trained males using traditional and PEN methods of dietary assessment.

The objectives to fulfil this aim were analysed by the following:

1. Traditional method of dietary assessment
   - To examine the patterns and/or adequacy of daily energy, nutrient intakes and frequency of EO in comparison to daily recommended values (see Chapter 4), for 7 days of recording, training and rest days
   - To investigate the patterns and adequacy of protein intake per EO (quantity and frequency) by comparison to the recommended values (see Chapter 4)

2. PEN method of dietary assessment
   - To examine the adequacy of protein intake patterns (i.e. quantity, time, distribution and frequency) per EO pre- during and post-RT (peri-RT). Comparison was made to the evidence-based, optimal peri-RT prescription for protein provided in Chapter 4 (for a summary see Table 12)
   - To examine the quantity of carbohydrate co-ingestion per EO peri-RT when protein intake was considered suboptimal.

5.5. Methods
The inclusion criteria for participants recruited in this study are described in Chapter 3, Section 3.4. The general information about methodology and methods used for data collection, entry and data analysis are presented in Chapter 3, Section 3.5–3.10. Details of the PEN analysis specific to RT adaptation are provided in Section 5.5.2. and evidence-based, recommended dietary intake in support of hypertrophy, strength gain and optimal health is summarised in Chapter 4, Table 13.

5.5.1. Participants’ Recruitment
A flowchart for the recruitment of resistance-trained males to examine the adequacy of dietary intakes using traditional dietary assessment (N = 37) and PEN assessment (N = 32) methods is presented in Figure 7.
Figure 7 Flowchart of participants’ recruitment through to data analysis

*Note. RT—Resistance training*

5.5.2. *PEN Analysis in Support of RT*

The analysis of nutrient intake in support of muscle hypertrophy and strength gain addressed protein and carbohydrate intake one hour before, during and up to 24 hours after RT in three-hour time intervals (Table 14). Additionally, protein intake within one hour before bedtime was assessed within pre-, during- and post-RT phases. When another RT occurred within the post-RT phase of a previous RT session, the start and endpoints of dietary data analysis were determined according to a decision tree for PEN data analysis (see Chapter 2, Figure 3). The start time of an RT session that occurred within 24 hours post-RT phase stopped the post-RT phase of dietary analysis of the previous RT session and shortened the intended 24 hours duration of dietary analysis post-RT for the first session. Therefore, the second RT session that occurred
within 24 hours consisted of the during- and post-training phase. The one-hour pre-RT phase for the second session was not assessed since it belonged to the post-training phase of the previous RT session. The characterisation of pre-, during- and post-RT phases is outlined in Table 14.

Table 14 Temporal patterns of PEN analysis of nutrient intakes in support of RT adaptation

<table>
<thead>
<tr>
<th>PEN phases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-RT</td>
<td>All EO consumed from ≤ 1 hour pre-RT up to the recorded time of the beginning of an RT session (exclusive). EO were identified if they did not overlap with the post-recovery phase of another RT session.</td>
</tr>
<tr>
<td>During-RT</td>
<td>All EO consumed between the recorded start-time of RT (inclusive) and the recorded end-time of the same training session (exclusive).</td>
</tr>
<tr>
<td>Post-RT</td>
<td>All EO consumed between the recorded end-time of RT (inclusive) and up to 24 hours post-RT (inclusive) in three-hour time intervals.</td>
</tr>
<tr>
<td>Pre-bedtime</td>
<td>All EO consumed from ≤ 1 hour before recorded bedtime (exclusive). The analysis included EO identified within either pre-, during- or post-RT phase.</td>
</tr>
</tbody>
</table>

Note. EO–Eating occasion; PEN–Peri-exercise nutrition; RT–Resistance training.

5.6. Results

5.6.1. Participants

The anthropometric profile of participants is presented in Table 15. Thirty-five participants gave their consent for body mass, height and body composition measurement. Two participants reported independently-measured body mass and height.
Table 15 Anthropometric profile of participants

<table>
<thead>
<tr>
<th></th>
<th>7 days and RD (N = 37)</th>
<th>TD (N = 35)</th>
<th>PEN (N = 32)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y)</strong></td>
<td>24.9 (20.7–29.7)</td>
<td>24.9 (20.6–29.7)</td>
<td>25.1 (20.9–30.3)</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>180.7 (6.8)</td>
<td>180.4 (6.7)</td>
<td>180.9 (11.3)</td>
</tr>
<tr>
<td><strong>Body mass (kg)</strong></td>
<td>81.3 (11.8)</td>
<td>80.7 (11.7)</td>
<td>81.9 (11.3)</td>
</tr>
<tr>
<td><strong>Lean tissue mass (kg)</strong></td>
<td>63.9 (7.6)</td>
<td>63.6 (7.7)</td>
<td>64.3 (7.4)</td>
</tr>
<tr>
<td><strong>Fat free mass (kg)</strong></td>
<td>67.4 (7.9)</td>
<td>67.1 (8.0)</td>
<td>67.7 (7.7)</td>
</tr>
<tr>
<td><strong>Fat mass (%)</strong></td>
<td>18.2 (4.7)</td>
<td>18.1 (4.4)</td>
<td>18.1 (4.5)</td>
</tr>
</tbody>
</table>

Note. Data are means (SD), other than for age that is reported as median (25th–75th percentiles). Body composition values are reported based on data of N = 35 for seven days, N = 33 for TD and N = 31 for PEN. PEN—Peri-exercise nutrition; RD—Rest days; TD—Training days.

Of the 37 participants, 35 trained that week. Two subjects, who did not train during the recording week, confirmed that their dietary intake was habitual. Thus, these 37 dietary records were included in the analysis for 7 days and RD. Table 16 outlines further information about participants’ weekly training programmes. Two subjects recorded a competition event in team sports on one occasion each. Because the aim was to assess the adequacy of nutrient intakes within the training microcycle, the data of two competition days were excluded from analysis.

Table 16 Characteristics of participants’ 7-day training and non-training activities

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>25th–75th Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of RD</strong></td>
<td>3</td>
<td>1–4</td>
</tr>
<tr>
<td><strong>Number of TD</strong></td>
<td>4</td>
<td>3–6</td>
</tr>
<tr>
<td><strong>Number of RT sessions</strong></td>
<td>3</td>
<td>2–5</td>
</tr>
<tr>
<td><strong>Number of training sessions, other than RT</strong></td>
<td>1</td>
<td>0–2</td>
</tr>
<tr>
<td><strong>Duration of an RT session (hh:mm)</strong></td>
<td>01:18</td>
<td>01:00–01:40</td>
</tr>
<tr>
<td><strong>Duration of a training session (all types) (hh:mm)</strong></td>
<td>01:14</td>
<td>00:58–01:30</td>
</tr>
</tbody>
</table>

Note. Data are normally distributed (P > .05). Mean (SD) for number of RT sessions is 3 (2); the duration of RT specific session is 01:22 (00:27) hh:mm; the duration of training session (all types) is 01:17 (00:27) hh:mm. RD—Rest Days; RT—Resistance training; TD—Training Days.
5.6.2. Traditional Analysis of Dietary Intake

Mean daily energy and macronutrient intakes, and frequency of EO for 7 days, TD, and RD, together with analysis of their adequacy, is provided in Table 17. According to the recommended macronutrient intakes as described in Chapter 4, the values that lay within the recommended range were classified as those that met daily recommendations [i.e. protein 1.6–2.2 g·kg⁻¹·d⁻¹, fat 20–35% of total energy intake (TEI), and carbohydrate 5–7 g·kg⁻¹·d⁻¹ for TD and 4–6 g·kg⁻¹·d⁻¹ for RD]. Based on daily recommended energy availability of 45 kcal·kg of fat free mass (FFM), available data of FFM for 35 subjects and values for recommended protein and fat intake, the averaged range of carbohydrate intake requirements on RD was calculated to be 4 (0.4)–6 (0.5) g·kg⁻¹·d⁻¹. Data that met lower but exceeded upper recommended thresholds were not included in Table 17. Analysis revealed that 30% (N = 11) of participants within the 7-day period, 49% (N = 17) on TD, and 27% (N = 10) on RD, exceeded the upper recommended protein intake. Analysis of carbohydrate intake indicated that no participant exceeded higher recommended intake of 7 g·kg⁻¹·d⁻¹ on TD nor exceeded 6 g·kg⁻¹·d⁻¹ of carbohydrate intake on RD. Additionally, 38% (N = 14) of participants within the 7-day record, 43% (N = 15) on TD and 51% (N = 19) on RD, exceeded daily fat intake requirements. The remaining participants did not meet the lower recommended threshold of macronutrient intake. All subjects consumed at least three EO per day [i.e. 5 (4–6) for 7 days, 5 (5–6) on TD and 5 (4–5) on RD], with a majority of subjects consuming more than four EO daily, over 7 days (86%, N = 32), TD (91%, N = 32) and RD (65%, N = 24).
Table 17 Adequacy of 7-day averaged energy and macronutrient intakes

<table>
<thead>
<tr>
<th>Energy and macronutrient intakes</th>
<th>Daily intake</th>
<th>Met daily recommendations (%, N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 days (N = 37)</td>
<td>TD (N = 35)</td>
</tr>
<tr>
<td>Energy (kcal·kg⁻¹·d⁻¹)</td>
<td>35 (7)</td>
<td>36 (7)</td>
</tr>
<tr>
<td>Protein (g·kg⁻¹·d⁻¹)</td>
<td>1.9 (0.5)</td>
<td>2.1 (0.5)</td>
</tr>
<tr>
<td>Carbohydrate (g·kg⁻¹·d⁻¹)</td>
<td>3.5 (1.0)</td>
<td>3.5 (1.1)</td>
</tr>
<tr>
<td>Fat (g·kg⁻¹·d⁻¹)</td>
<td>1.3 (0.4)</td>
<td>1.4 (0.4)</td>
</tr>
<tr>
<td>Fat (% TEI·d⁻¹)</td>
<td>35 (5)</td>
<td>34 (7)</td>
</tr>
</tbody>
</table>

Note. Data are means (SD). ¹The adequacy of carbohydrate intake on RD was assessed for N = 35 subjects of whom fat-free mass was known. N/A–Not applicable; RD–Rest days; TD–Training days; TEI–Total energy intake.
Protein intake per main EO and snack, together with their frequency, is presented in Table 18. Protein intake per main EO exceeded 0.5 g·kg\(^{-1}\) for 51% \((N = 19)\), 49% \((N = 17)\) and 49% \((N = 18)\) of subjects within the 7 days, TD and RD, respectively. However, protein intake per snack was below 0.3 g·kg\(^{-1}\) for 78% \((N = 29)\), 74% \((N = 26)\) and 81% \((N = 30)\) of subjects within the 7 days, TD and RD, respectively. Participants reported the same daily frequency of consuming main EO [i.e. 3 (3–3)] for 7 days, TD and RD. The reported frequency of snacks consumed was 2 (2–3) within the 7-day record, 3 (2–4) on TD and 2 (1–3) on RD.

Table 18 Adequacy of protein intake per EO

<table>
<thead>
<tr>
<th>Type of EO</th>
<th>7 days ((N = 37))</th>
<th>TD ((N = 35))</th>
<th>RD ((N = 37))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reported protein intake per EO (g·kg(^{-1})·EO(^{-1}))</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main EO</td>
<td>0.5 (0.4–0.6)</td>
<td>0.5 (0.4–0.6)</td>
<td>0.5 (0.4–0.6)</td>
</tr>
<tr>
<td>Snacks</td>
<td>0.2 (0.1–0.3)</td>
<td>0.2 (0.1–0.3)</td>
<td>0.2 (0.1–0.3)</td>
</tr>
<tr>
<td><strong>Met protein intake recommendations per EO (%)(^,) N</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main EO</td>
<td>43%, (N = 16)</td>
<td>49%, (N = 17)</td>
<td>41%, (N = 15)</td>
</tr>
<tr>
<td>Snacks</td>
<td>22%, (N = 8)</td>
<td>23%, (N = 8)</td>
<td>16%, (N = 6)</td>
</tr>
</tbody>
</table>

*Note. Data are medians \((25^{th}–75^{th} \text{percentiles})\) for protein quantity \((\text{g·kg}^{-1} \cdot \text{EO}^{-1})\). EO–Eating occasion; RD–Rest days; TD–Training days.*

Fibre, cholesterol, omega-3 fatty acids and micronutrient intakes for 7 days are presented in Table 19. The adequacy of reported values for each participant was examined by comparison to daily dietary recommendations from the Institute of Medicine (2000a; 2011) summarised in Table 10 in Chapter 4. Less than 60% of participants achieved the recommended intake for fibre, potassium, magnesium, Vitamins A, D, E, and K, and folates.
Table 19 Adequacy of 7-day nutrient intake compared to Institute of Medicine (2000a; 2011) recommendations.

<table>
<thead>
<tr>
<th>Type of nutrient intake</th>
<th>7 days (N = 37)</th>
<th>Participants who met recommended intake (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre (AOAC) (g·day⁻¹)</td>
<td>27 (23–34)</td>
<td>16%, N = 6</td>
<td></td>
</tr>
<tr>
<td>Omega-3 fatty acids (g·day⁻¹)</td>
<td>1.4 (0.9–2.4)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Cholesterol (mg·day⁻¹)</td>
<td>496 (346–777)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Sodium (mg·day⁻¹)</td>
<td>3108 (2493–3411)</td>
<td>97%, N = 36</td>
<td></td>
</tr>
<tr>
<td>Potassium (mg·day⁻¹)</td>
<td>4191 (3408–5316)</td>
<td>32%, N = 12</td>
<td></td>
</tr>
<tr>
<td>Calcium (mg·day⁻¹)</td>
<td>1106 (879–1480)</td>
<td>68%, N = 25</td>
<td></td>
</tr>
<tr>
<td>Magnesium (mg·day⁻¹)</td>
<td>452 (349–585)</td>
<td>59%, N = 21</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (mg·day⁻¹)</td>
<td>2036 (1600–2526)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Iron (mg·day⁻¹)</td>
<td>17 (12–22)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Copper (mg·day⁻¹)</td>
<td>2.1 (1.6–2.8)</td>
<td>97%, N = 36</td>
<td></td>
</tr>
<tr>
<td>Zinc (mg·day⁻¹)</td>
<td>14 (11–21)</td>
<td>78%, N = 29</td>
<td></td>
</tr>
<tr>
<td>Chloride (mg·day⁻¹)</td>
<td>4826 (3915–5504)</td>
<td>97%, N = 36</td>
<td></td>
</tr>
<tr>
<td>Manganese (mg·day⁻¹)</td>
<td>4.7 (3.2–6.7)</td>
<td>95%, N = 35</td>
<td></td>
</tr>
<tr>
<td>Selenium (µg·day⁻¹)</td>
<td>79 (65–103)</td>
<td>81%, N = 30</td>
<td></td>
</tr>
<tr>
<td>Iodine (µg·day⁻¹)</td>
<td>195 (128–266)</td>
<td>65%, N = 24</td>
<td></td>
</tr>
<tr>
<td>Vitamin A (µg·day⁻¹)</td>
<td>1336 (603–2023)</td>
<td>59%, N = 22</td>
<td></td>
</tr>
<tr>
<td>Vitamin D (µg·day⁻¹)</td>
<td>5 (4–10)</td>
<td>51%, N = 19</td>
<td></td>
</tr>
<tr>
<td>Vitamin E (mg·day⁻¹)</td>
<td>15 (10–20)</td>
<td>57%, N = 21</td>
<td></td>
</tr>
<tr>
<td>Vitamin K₁ (µg·day⁻¹)</td>
<td>78 (26–131)</td>
<td>27%, N = 10</td>
<td></td>
</tr>
<tr>
<td>Vitamin B₁ (mg·day⁻¹)</td>
<td>2.1 (1.8–3.3)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Vitamin B₂ (mg·day⁻¹)</td>
<td>2.7 (2.0–3.8)</td>
<td>97%, N = 36</td>
<td></td>
</tr>
<tr>
<td>Niacin (mg·day⁻¹)</td>
<td>37 (29–49)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Pantothenic acid (mg·day⁻¹)</td>
<td>11 (9–15)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Vitamin B₆ (mg·day⁻¹)</td>
<td>3.9 (3.0–5.3)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Biotin (µg·day⁻¹)</td>
<td>63 (37–89)</td>
<td>89%, N = 33</td>
<td></td>
</tr>
<tr>
<td>Folates (µg·day⁻¹)</td>
<td>394 (275–487)</td>
<td>46%, N = 17</td>
<td></td>
</tr>
<tr>
<td>Vitamin B₁₂ (µg·day⁻¹)</td>
<td>9.6 (6.7–12.9)</td>
<td>100%, N = 37</td>
<td></td>
</tr>
<tr>
<td>Vitamin C (mg·day⁻¹)</td>
<td>110 (84–201)</td>
<td>65%, N = 24</td>
<td></td>
</tr>
</tbody>
</table>

Note. Data are medians (25th–75th percentiles). ¹ Retinol equivalent. AOAC—American Association of Analytical Chemists.
5.6.3. **PEN Analysis of Dietary Intake Tailored to RT**

The median duration of the RT sessions included in the analysis \((N = 118)\) was 01:30 (01:00–02:00) hh:mm. Of the 118 RT sessions, 52% \((N = 61)\) were followed by a 24-hour post-training phase within which no further RT was performed. The median duration of the post-RT phase was 24:00 (20:19–24:00) hh:mm, of which 08:00 (06:49–09:00) hh:mm were in sleep.

Figure 8 outlines the pathway to 118 RT sessions for which the PEN analysis was conducted. Protein and carbohydrate intake was assessed for each EO consumed one hour pre-, during RT in Table 20, and up to 24 hours post-RT in Table 21. Protein intake was analysed for each EO consumed one hour before bedtime in Table 22.

Table 20 PEN analysis of protein and carbohydrate intake pre- and during RT

<table>
<thead>
<tr>
<th>Time of EO (hh:mm)(^1)</th>
<th>1 hour pre-RT ((N = 31))</th>
<th>During-RT ((N = 20))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00:35 (00:30–01:00)</td>
<td>00:30 (00:00–01:37)</td>
</tr>
<tr>
<td>Protein intake (g·kg(^{-1})·EO(^{-1}))(^1)</td>
<td>0.2 (0.0–0.5)</td>
<td>0.2 (0.0–0.6)</td>
</tr>
<tr>
<td>Protein intake (g·kg(^{-1})·EO(^{-1})) &lt; 0.3 g·kg(^{-1})·EO(^{-1})(^2)</td>
<td>0.1 (0.0–0.1)</td>
<td>0 (0.0–0.2)</td>
</tr>
<tr>
<td>Carbohydrate intake (g·kg(^{-1})·EO(^{-1})) &lt; 0.3 g·kg(^{-1})·EO(^{-1})(^2)</td>
<td>0.1 (0.0–0.4)</td>
<td>0 (0.0–0.6)</td>
</tr>
<tr>
<td>Frequency of all EO (EO·RT(^{-1}))(^1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>Number of all EO</td>
<td>31</td>
<td>21</td>
</tr>
<tr>
<td>Number of EO &lt; 0.3 g·kg(^{-1})·EO(^{-1})(^2)</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Number of RT &lt; 0.3 g·kg(^{-1})·EO(^{-1})(^3)</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>

**Note.** All RT sessions \((N = 118)\) were screened for EO pre- and during-RT phases.

\(^1\)Data are medians \((25^{th}–75^{th} \text{ percentiles})\); \(^2\) < 0.3 g·kg\(^{-1}\)·EO\(^{-1}\) indicates results of analysis of those EO for which protein intake was below given value; \(^3\) Number of RT < 0.3 g·kg\(^{-1}\)·EO\(^{-1}\) indicates number of RT sessions, for which < 0.3 g·kg\(^{-1}\) of protein was consumed in at least one EO. EO–Eating occasion/s; PEN–Peri-exercise nutrition; RT–Resistance training.
Figure 8 Flowchart of PEN analysis of resistance training (N = 118)

Note. EO—Eating occasion/s; PEN—Peri-exercise nutrition; RT—Resistance training.
Table 21 PEN analysis of protein and carbohydrate intake post-RT in three-hour time intervals

<table>
<thead>
<tr>
<th></th>
<th>0–3 h (N=109)</th>
<th>3–6 h (N=53)</th>
<th>6–9 h (N=34)</th>
<th>9–12 h (N=44)</th>
<th>12–15 h (N=57)</th>
<th>15–18 h (N=46)</th>
<th>18–21 h (N=61)</th>
<th>21–24 h (N=55)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of EO (hh:mm)¹</td>
<td>(00:50)</td>
<td>(04:30)</td>
<td>(07:37)</td>
<td>(10:44)</td>
<td>(13:30)</td>
<td>(16:42)</td>
<td>(19:30)</td>
<td>(22:20)</td>
</tr>
<tr>
<td>Protein intake (g·kg⁻¹·RT⁻¹·3h⁻¹)¹</td>
<td>0.7 (0.4–1.0)</td>
<td>0.5 (0.2–0.8)</td>
<td>0.4 (0.1–0.7)</td>
<td>0.3 (0.1–0.5)</td>
<td>0.3 (0.2–0.5)</td>
<td>0.5 (0.2–0.7)</td>
<td>0.4 (0.2–0.6)</td>
<td>0.4 (0.2–0.6)</td>
</tr>
<tr>
<td>Protein intake (g·kg⁻¹·EO⁻¹)¹</td>
<td>0.4 (0.3)</td>
<td>0.3 (0.1–0.7)</td>
<td>0.4 (0.1–0.6)</td>
<td>0.3 (0.1–0.4)</td>
<td>0.3 (0.2–0.6)</td>
<td>0.4 (0.1–0.5)</td>
<td>0.3 (0.1–0.5)</td>
<td>0.3 (0.1–0.5)</td>
</tr>
<tr>
<td>Protein intake (g·kg⁻¹·EO⁻¹) ≥ 0.3 g·kg⁻¹·EO⁻¹¹,²</td>
<td>0.5 (0.4–0.7)</td>
<td>0.6 (0.4–0.9)</td>
<td>0.6 (0.5–0.8)</td>
<td>0.6 (0.4–0.8)</td>
<td>0.6 (0.4–0.5)</td>
<td>0.4 (0.4–0.7)</td>
<td>0.6 (0.4–0.6)</td>
<td>0.5 (0.4–0.7)</td>
</tr>
<tr>
<td>Protein intake (g·kg⁻¹·EO⁻¹) &lt; 0.3 g·kg⁻¹¹,³</td>
<td>0.2 (0.1–0.2)</td>
<td>0.1 (0–0.1)</td>
<td>0.1 (0–0.2)</td>
<td>0.2 (0–0.2)</td>
<td>0.2 (0–0.2)</td>
<td>0.2 (0–0.2)</td>
<td>0.1 (0–0.2)</td>
<td>0.1 (0–0.2)</td>
</tr>
<tr>
<td>Carbohydrate intake (g·kg⁻¹·EO⁻¹) &lt; 0.3 g·kg⁻¹¹,³</td>
<td>0.4 (0.1–0.7)</td>
<td>0.3 (0–0.1)</td>
<td>0.2 (0–0.2)</td>
<td>0.3 (0–0.2)</td>
<td>0.3 (0–0.2)</td>
<td>0.3 (0–0.2)</td>
<td>0.3 (0–0.2)</td>
<td>0.3 (0–0.2)</td>
</tr>
<tr>
<td>Frequency of EO (EO·RT⁻¹·3h⁻¹)¹</td>
<td>2 (1–2)</td>
<td>1 (1–2)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–2)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>Frequency of EO (EO·RT⁻¹·3h⁻¹) ≥ 0.3 g·kg⁻¹¹,²</td>
<td>1 (1–2)</td>
<td>1 (1–2)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>Number of EO (EO·3h⁻¹)</td>
<td>177</td>
<td>75</td>
<td>38</td>
<td>49</td>
<td>70</td>
<td>60</td>
<td>74</td>
<td>65</td>
</tr>
<tr>
<td>Number of EO (EO·3h⁻¹) ≥ 0.3 g·kg⁻¹²</td>
<td>123</td>
<td>39</td>
<td>21</td>
<td>19</td>
<td>29</td>
<td>36</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Number of RT (RT·3h⁻¹) ≥ 0.3 g·kg⁻¹³</td>
<td>92</td>
<td>36</td>
<td>20</td>
<td>19</td>
<td>28</td>
<td>32</td>
<td>39</td>
<td>31</td>
</tr>
<tr>
<td>Number of RT (RT·3h⁻¹) &lt; 0.3 g·kg⁻¹⁴</td>
<td>44</td>
<td>30</td>
<td>17</td>
<td>29</td>
<td>36</td>
<td>20</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>Total number of RT⁵</td>
<td>118</td>
<td>118</td>
<td>114</td>
<td>111</td>
<td>106</td>
<td>99</td>
<td>98</td>
<td>86</td>
</tr>
</tbody>
</table>

Note. All RT sessions (N = 118) were screened for EO in post-RT phases. The table heading indicates number of RT sessions after which at least one EO was consumed in a post-RT phase in a given three-hour time interval. ¹Data are medians (25⁰–75⁰ percentiles); ²≥ 0.3 g·kg⁻¹·EO⁻¹—indicates results of analysis of those EO for which protein intake was equal or above given value; ³< 0.3 g·kg⁻¹·EO⁻¹—indicates results of analysis of those EO for which protein intake was below given value; ⁴Number of RT ≥ 0.3 g·kg⁻¹·EO⁻¹—indicates number of RT sessions, after which ≥ 0.3 g·kg⁻¹ of protein was consumed in at least one EO; ⁵Number of RT < 0.3 g·kg⁻¹·EO⁻¹—indicates number of RT sessions, after which < 0.3 g·kg⁻¹ of protein was consumed in at least one EO; ⁶Total number of RT—Number of RT sessions, which post-RT phase lasted within a given three-hour time interval. The total number of RT value includes RT sessions after which either EO was consumed or not. EO—Eating occasion; PEN—Peri-exercise nutrition; RT—Resistance training.
Overall, 2.0 (1.4–2.4) g·kg⁻¹ of protein was consumed post-RT. Median protein intake per EO was 0.3 (0.1–0.5) g·kg⁻¹ post-RT. Moreover, eating occasions for which ≥ 0.3 g·kg⁻¹ of protein was consumed were analysed. Results revealed that protein intake for these EO was 0.5 (0.4–0.7) g·kg⁻¹. When less than 0.3 g·kg⁻¹ of protein was consumed per EO, participants consumed 0.1 (0–0.2) g·kg⁻¹ of protein and 0.4 (0.1–0.7) g·kg⁻¹ of carbohydrate. Median frequency of EO post-RT was 5 (4–6) EO, of which 3 (2–4) of EO provided ≥ 0.3 g·kg⁻¹ of protein and 2 (1–3) of EO provided < 0.3 g·kg⁻¹ of protein. Distribution of EO when at least two EO were consumed within the post-RT phase (N = 116) was 02:20 (01:30–03:29) hh:mm. The recommended distribution of EO between three and five hours was achieved in 29% (N = 118) of cases post-RT (N = 402).

Table 22 PEN analysis of protein intake pre-bedtime

<table>
<thead>
<tr>
<th>Time of EO pre-bedtime (hh:mm)</th>
<th>Protein intake (g·kg⁻¹·EO⁻¹)</th>
<th>Protein intake (g·kg⁻¹·EO⁻¹) &lt; 0.5 g·kg⁻¹ · EO⁻¹</th>
<th>Frequency of all EO (EO·RT⁻¹)</th>
<th>Number of EO</th>
<th>Number of EO &lt; 0.5 g·kg⁻¹</th>
<th>Number of RT &lt; 0.5 g·kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:45 (00:30–01:00)</td>
<td>0.3 (0.1–0.3)</td>
<td>0.2 (0–0.3)</td>
<td>1 (1–1)</td>
<td>24</td>
<td>19</td>
<td>18</td>
</tr>
</tbody>
</table>

Note. All RT sessions (N = 118) were screened for EO in pre-bedtime phases. ¹Data are medians (25th–75th percentiles); ²< 0.5 g·kg⁻¹·EO⁻¹—indicates results of analysis of those EO for which protein intake was below given value; ³Number of RT < 0.5 g·kg⁻¹·EO⁻¹—indicates number of RT sessions, for which protein intake per EO was < 0.5 g·kg⁻¹. EO—Eating occasion; RT—Resistance training.

5.7. Discussion

Researchers (Burke et al. 2003; Magkos and Yannakoula 2003; MacKenzie et al. 2015; Larson-Meyer et al. 2018) acknowledge that it is challenging to examine the eating patterns of the athletic population due to the absence of standardised methodology. However, information about trained and athletic populations eating patterns is needed to evaluate the adequacy of nutrient intake to evidence-based
recommendations, to recognise opportunities for improvement of dietary intake in support of training adaptation and sports performance, and to inform further research designs. The application of advanced dietary assessment research is limited, mainly to endurance athletes (Burke et al. 2003; MacKenzie et al. 2015; Heikura et al. 2018a; Heikura et al. 2019). To the author’s knowledge, there is only one research study that reported protein intake and number of EO in proximity to RT, i.e. post-RT sessions (i.e. after 8 pm, within the same day) for rugby players (MacKenzie et al. 2015). This current study aimed to examine the patterns and adequacy of dietary practices of a homogenous cohort of men with at least six months of RT experience using traditional and PEN assessment. Additionally, the analysis presented in this chapter is the first example of applying the PEN approach to examine the adequacy of nutrient intakes, according to time, goal and type of training session, in line with the evidence-based recommendations of nutrient intakes.

5.7.1. Traditional Analysis of Dietary Intake

Specific to the aim identified in Section 5.4., the patterns and adequacy of energy and nutrient intakes, and the frequency of EO were analysed according to daily and per EO recommended values (see Chapter 4). The absence of direct measurement of total energy expenditures and failure to collect the intensity of exercise sessions, did not allow for the analysis of adequacy of energy availability.

The adequacy of participants’ average daily protein intake was examined by comparison to the recommended range of 1.6–2.2 g·kg⁻¹·d⁻¹ for this population (Maughan et al. 2018). Within this range, less than 45% of participants achieved the recommended intake average of 7 days, TD and RD. However, 73% (N = 27) of participants within the 7-day recording, 80% (N = 28) on TD and 62% (N = 23) on RD, met the lower recommended protein intake threshold of 1.6 g·kg⁻¹·d⁻¹. On this basis, most participants met the minimum requirement for daily protein intake. However, the reported excess of protein intake will not further maximise muscle hypertrophy (Davies et al. 2020) but increase overall protein catabolism (Pencharz et al. 2008). Protein intake of 0.3–0.5 g·kg⁻¹·EO⁻¹ on 3–4 occasions per day and in close proximity to RT is considered optimal for maximising muscle hypertrophy (Maughan et al. 2018). According to these recommendations, further investigation of patterns of protein intake per EO revealed that at least 90% of participants met (0.3–0.5 g·kg⁻¹·EO⁻¹) or exceeded (> 0.5 g·kg⁻¹·EO⁻¹) the recommended protein intake that was
consumed per main EO for 7-day recording, TD and RD. Nevertheless, more than 70% of subjects did not consume 0.3 g·kg⁻¹·EO⁻¹ of protein with their snacks during the 7 days, TD or RD. On average, snacks provided 0.2 (0.1–0.3) g·kg⁻¹·EO⁻¹ of protein. The quantity of protein intake per main EO and snacks suggests that main EO not snacks, were tailored to support RT adaptation. Based on traditional dietary analysis, with no-indication of EO proximity to RT, the median frequency [3 (3–3)] and quantity of protein intake per main EO [0.5 (0.4–0.6)] indicate that most of participants met protein intake requirements per EO in support of muscle hypertrophy over the 7-day recording phase.

In this study, the inability to validate TEI versus total energy expenditure did not allow for the development of carbohydrate intake recommendations tailored to exercise energy expenditure for TD. Thus, carbohydrate intake recommendations for TD were set at 5–7 g·kg⁻¹·d⁻¹ according to the average duration of training sessions, i.e. > 1 hour (Thomas et al. 2016). Only 14% (N = 5) of subjects (N = 35) on TD achieved carbohydrate intake adequacy in relation to these requirements. Other subjects (N = 30) consumed less than 5 g·kg⁻¹·d⁻¹ of carbohydrate on TD. The average recommended carbohydrate intake of 4–6 g·kg⁻¹·d⁻¹ on RD was consistent with optimal energy availability of 45 kcal g·kg FFM⁻¹·d⁻¹ (Loucks et al. 2011), recommended daily protein (i.e. 1.6–2.2 g·kg⁻¹·d⁻¹) and fat (i.e. 20–35% of TEI) intake. On that premise, 20% (N = 7) of subjects (N = 35) met carbohydrate intake requirements on RD, which was comparable to percentage of individuals who met carbohydrate intake recommendations on TD. The average carbohydrate intake was lower than for high-performance athletes from different sports disciplines, i.e. > 5 g·kg⁻¹·d⁻¹ (Burke et al. 2003; Erdman et al. 2013).

Based on daily recommended fat intake of 20–35% of TEI (Thomas et al. 2016), participants’ average ~35% of fat intake (Table 17) for seven days TD and RD mirrored the higher-end of intake recommendations. Of the 37 participants, 62% (N = 23) met the recommended range and 38% (N = 14) of participants exceeded the upper recommended threshold of fat intake (i.e. 35% of TEI). Thus, in line with daily recommendations, fat intake might be considered as high in comparison to carbohydrate intake.
Daily adequacy of fibre and micronutrient intakes for each individual was assessed according to the Recommended Dietary Allowances (RDA) or Adequate Intakes (AI) (when RDA were not established). Dietary Reference Intakes (DRI) were achieved for 46% \((N = 12)\) of the assessed intake of micronutrients and fibre \((N = 26)\) by at least 90% \((N = 33)\) of the subjects \((N = 37)\). When this analysis was provided for recommended intake of microelements responsible for maintaining normal muscle function, i.e. calcium, magnesium, potassium and sodium \((\text{Turck et al. 2018})\), adequacy of sodium intake was identified as the sole micronutrient achieved by 97% \((N = 36)\) of resistance-trained males.

### 5.7.2. PEN Analysis of Dietary Intake Tailored to RT

A PEN analysis was conducted to assess the adequacy of habitual protein and carbohydrate intake in proximity to RT (i.e. one hour pre-, during and up to 24 hours post-RT, and within one hour pre-bedtime). Carbohydrate intake was assessed for those EO for which protein intake was \(< 0.3 \text{ g·kg}^{-1}·\text{EO}^{-1}\).

Consumption of protein intake pre-RT is an important consideration in the PEN analysis since either pre- or post-RT protein intake affects muscle protein synthesis (MPS) similarly \((\text{Tipton et al. 2007})\). From a practical point of view, consumption of either fast- or slow-digested protein sources before RT stimulate MPS above basal rates comparably \([0.085 (0.013) \%\cdot\text{h}^{-1} \text{ versus } 0.095 (0.010) \%\cdot\text{h}^{-1}\) for fast and slow-digested protein, respectively \((P = .56)\) \((\text{Burke et al. 2012a})\). A pre-EO was reported before 26% \((N = 31)\) of the RT sessions \((N = 118)\). The pre-RT median protein intake was 0.2 \((0–0.5) \text{ g·kg}^{-1}·\text{EO}^{-1}\). Over half \((58\%, N = 18)\) of reported EO pre-RT comprised suboptimal protein intake (i.e. \(< 0.3 \text{ g·kg}^{-1}·\text{EO}^{-1}\)) \((\text{Table 20})\). Hence, optimised protein intake was not a common practice pre-RT. The amount and timing of pre-RT protein intake should aim to prevent an overlap of aminoacidemia pre- and in the early post-RT phases, since it may blunt the MPS response to an additional amino acid provision \((\text{Atherton et al. 2010; Morton et al. 2015})\). Therefore, the distribution of protein intake peri-RT should be carefully planned.

Since the MPS response during an RT session is attenuated \((\text{Kumar et al. 2009})\), the requirement for optimal protein intake close to either pre- or post-RT \((\text{Tipton et al. 2001})\) or distributed between three and five hours apart, both pre- and post-RT protein intake may favour MPS \((\text{Moore et al. 2009b; Areta et al. 2013})\). Eating occasions were
consumed during 17% \((N = 20)\) of the RT sessions \((N = 118)\), of which less than 0.3 \(\text{g} \cdot \text{kg}^{-1}\) of protein was consumed during 60% \((N = 12)\) of these RT sessions \((N = 20)\). Comparably to protein intake pre-RT, optimised protein intake during RT was not a preferred strategy in this group of resistance-trained males.

The required protein intake for maximizing muscle hypertrophy within 24 hours post-RT is 1.6–2.2 \(\text{g} \cdot \text{kg}^{-1}\) (Maughan et al. 2018; Morton et al. 2018). In this study, the total protein intake within a post-RT phase was 2.0 (1.4–2.4) \(\text{g} \cdot \text{kg}^{-1}\). Independent of time of individual EO, and compared to the evidence based recommendations, the PEN analysis of protein intake revealed that for 56% \((N = 342)\) of reported EO \((N = 608)\), protein intake was adequate or greater than adequate to support the stated training adaptation. In contrast, 44% \((N = 266)\) of all EO \((N = 608)\) did not meet the recommended 0.3 \(\text{g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}\) of protein.

Protein intake within the first two hours post-RT is favoured in support of muscle mass increase over time (Hartman et al. 2007). Considering the evaluation of protein intake up to 24 hours post-RT in support of MPS (Burd et al. 2011; Churchward-Venne et al. 2012b), protein intake of 0.3–0.5 \(\text{g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}\) (Maughan et al. 2018; Witard et al. 2019) and distribution between three and five hours was set as optimal within waking hours (Moore et al. 2009; Areta et al. 2013). In the first three-hour time interval post-RT, on average EO was consumed at 00:50 (00:15–02:00) hh:mm post-training. The PEN analysis for this period of time revealed that frequency of EO reported after 92% \((N = 109)\) of all RT sessions \((N = 118)\) was 2 (1–2). Median protein intake of 0.7 (0.4–1.0) \(\text{g} \cdot \text{kg}^{-1} \cdot \text{3h}^{-1}\) exceeded the recommendation per single EO. However, quantity of protein intake was suboptimal in one-third of EO within the first three hours post-RT. Nevertheless, excess protein intake was reported within the first three hours post-RT and no EO was consumed for 8% \((N = 9)\) of all RT sessions \((N = 118)\) (Table 21). Whether intentional or not, the overfeeding of protein would not be seen to further increase lean tissue mass but to induce an overall increase in protein catabolism (Bohe et al. 2001; Atherton et al. 2010). Despite the multiple occasions of protein intake during this post-RT phase, the research evidence supports one bolus (~25 g of protein) for optimising MPS (West et al. 2011; Areta et al. 2013). Moreover, protein overfeeding does not further increase lean tissue mass but induces protein catabolism (Bohe et al. 2001; Atherton et al. 2010).
In the next three hours (3–6 hours) post-RT, the number of EO consumed decreased twice, the same as the number of RT after which an EO was consumed (Table 21). The second time interval, within which the most number of RT (N = 61) were supported by EO, was 18–21 hours post-RT (N = 98) (Table 21). Between 3 and 24 hours post-exercise, EO were reported in 30–64% of post-RT phases that were identified in the analysed three-hour time intervals. Overall, the median number of EO recorded up to 24 hours post-RT was 5 (4–6). Excluding sleep time within the 24-hour post-RT phase of analysis, the number of EO was reported within ~16 hours. Median number of EO that provided ≥ 0.3 g·kg⁻¹·EO⁻¹ of protein was 3 (2–4). Identified EO were distributed every 02:20 (01:30–03:29) hh:mm within waking hours and the recommended 3–5 hours spacing between EO was achieved in 29% (N = 118) cases post-RT (N = 402). Thus, despite the evidence of more frequent EO post-RT, the frequency of optimised protein quantity in EO lay within the recommended 3–4 EO post-RT (Maughan et al. 2018). It has been shown that 10 g of protein consumed every 1.5 hours (0.06 %·h⁻¹), as opposed to 20 g of protein consumed every three hours (0.079 %·h⁻¹), attenuates myofibrillar fractional synthetic rate by 0.019 %·h⁻¹ (32%) post-RT (Areta et al. 2013). Hence, on the one hand, the shorter time between EO could complement suboptimal protein intakes. On the other hand, as stated earlier, rapid instead of pulse aminoacidemia is advantageous for the maximal MPS response post-RT (West et al. 2011; Areta et al. 2013). The correction of protein quantity and distribution could be further optimised in line with the reported frequency of EO consumed within the 24-hour post-RT.

The previous discussion considered the adequacy of the feeding paradigm adopted within a 24-hour period of recovery post-RT. Yet, few studies have shown an increase in MPS at 24 hours post-RT following nutrient feeding (Tipton et al. 2003; Cuthbertson et al. 2006; Burd et al. 2011). Burd et al. (2011) conducted a research study with three different RT paradigms and provided subjects with a standardised liquid feeding at 24 hours post-RT. The study showed that myofibrillar protein synthesis was stimulated after the feeding post-RT when subjects trained to failure (two of three training protocols). The MPS response was greater after consumption of a standardised liquid meal (17 g protein, 69 g carbohydrate) at 24 hours post-RT [M (SE) 0.0038 (0.012) and 0.041 (0.010) %·h⁻¹] than after the same feeding at rest [M (SE) 0.016 (0.002) %·h⁻¹]. Despite participants receiving less than 20 g of protein, the
MPS response at 24 hours post-RT was higher by 138–156%, in comparison to the MPS response after EO at rest. In this current study, suboptimal protein intake of 0.1 (0–0.2) g·kg\(^{-1}\)·EO\(^{-1}\), identified within 21–24 hours post-RT, was consumed after 28 RT sessions and no EO were consumed after 31 RT of the 86 RT sessions. According to the research study by Burd et al. (2011), theoretically, optimisation of protein intake quantity to 25 g at 24 hours post-RT could increase myofibrillar protein synthesis to 0.057 %·h\(^{-1}\). Nevertheless, further research is required to examine this assumption.

The PEN analysis up to 24 hours post-RT included an overnight sleep period. Pre-sleep protein intake was shown to increase MPS overnight by 22% (Res et al. 2012). Thus, pre-sleep protein feeding of at least 40 g (≥ 0.5 g·kg\(^{-1}\)·EO\(^{-1}\)) has been proposed before a prolonged period of protein ingestion absence (> 6 hours) (Res et al. 2012; Trommelen and van Loon 2016). The PEN analysis identified that EO were consumed within one hour pre-bedtime for 21% (N = 23) of RT (N = 118). Median protein intake pre-bedtime was 0.3 (0.1–0.3), of which 79% (N = 19) of all reported EO (N = 24) were suboptimal in protein [0.2 (0–0.3) g·kg\(^{-1}\)·EO\(^{-1}\)], according to the recommended intake of > 0.5 g·kg\(^{-1}\)·EO\(^{-1}\) (Table 22).

Co-ingestion of carbohydrate is recommended when the amount of protein per EO is inadequate, since co-ingestion of carbohydrate intake can enhance muscle protein balance in the absence of protein (Borsheim et al. 2004). However, carbohydrate intake does not improve myofibrillar and sarcoplasmic muscle protein balance further when 25 g (~0.3 g·kg\(^{-1}\)) of protein is consumed per EO (Staples et al. 2011). In this study, suboptimal protein intake in 44% (N = 266) of all EO (N = 608), was supported with 0.4 (0.1–0.7) g·kg\(^{-1}\)·EO\(^{-1}\) of carbohydrate. Carbohydrate co-ingested with protein delays protein digestion and absorption but does not influence MPS, in comparison to protein intake alone at rest in young untrained individuals (Gorissen et al. 2014). Moreover, 0.5 g·kg\(^{-1}\)·EO\(^{-1}\) of carbohydrate can be consumed within one hour post-RT without negative effects on MPS (Miller et al. 2003). It was estimated that the addition of carbohydrate to an EO with no or suboptimal protein intake might enhance muscle protein balance by ~30% (Miller et al. 2003; Glynn et al. 2010).

In practical terms, the PEN analysis demonstrated that protein intake (quantity, time and distribution) could be improved to optimise the intended adaptive outcome of RT in resistance-trained individuals, according to the requirements for protein intake pre-
training, pre-sleep and throughout a 24-hour post-RT phase. The requirement for one protein-optimised EO every three to five hours post-RT forms the basis of the nutrient prescription that might be altered by individuals’ lifestyle, sleep and eating patterns. The optimised pattern of protein intake can benefit the training adaptation outcome. However, greater frequency of EO or amount of protein per EO above that considered optimal, is likely not to have a superior effect.

5.7.3. Complementary Role of PEN and Traditional Methods of Dietary Assessment for Trained Populations

The traditional dietary method of analysis provides information on the average daily and per EO energy and nutrient intakes. Daily and EO-by-EO collection of food intake data is a basic tool for examining the adequacy of athletes’ dietary practices. The traditional method of assessment of dietary data is not tailored to evaluate the adequacy of nutrient intake in proximity to training sessions but rather associates EO consumed with fixed time intervals throughout a day (e.g. breakfast, lunch, dinner, snacks). In contrast, performance nutrition recommends consideration of nutrient requirements associated with intended outcomes of training and competition that extends across the microcycles, mesocycles and macrocycles of exercise programmes (Thomas et al. 2016). The nutrient intake, exercise and intent considerations are fundamental to personalised and periodised approaches (Burke 2010; Thomas et al. 2016; Jeukendrup 2017; Burke and Hawley 2018; Burke et al. 2018). Therefore, the PEN approach places training stimulus and training intent as a central tenet of assessment, rather than chronology alone. Furthermore, within a sports discipline, the PEN approach focuses on matching the adequacy of nutrient intake to the specificity of training and training goals. Even though the PEN method of data collection does not vary substantially from traditional standards of data collection, the outcomes of traditional and PEN methods of dietary assessment had not been reported previously, nor to this level of detail. The outcome of this analysis has endorsed the provision of daily and per EO dietary information to assess the adequacy of nutrient provision in support an individual’s health, but also to conduct an evidence-based analysis of nutrient requirements specific to the training and intent. The PEN approach is proposed as complementary to and an advancement to the traditional dietary assessment method.
5.8. Conclusions
In conclusion, average daily and per main EO protein intake for 7 days, TD and RD, and number of EO by resistance-trained individuals were optimal to maximise muscle hypertrophy and strength gain. However, individual daily and per EO protein intake could be optimised by the subjects. On average, subjects under-fuelled their daily carbohydrate intake requirements. The micronutrient intakes recorded within 7 days could be further improved by individuals. The PEN analysis revealed that the frequency of EO was sufficient to provide optimised quantity and quality of protein to maximally stimulate MPS. Distribution of EO post-RT was more frequent than recommended. Theoretically, in this study co-ingestion of carbohydrate with suboptimal or no protein intake per EO could improve muscle protein balance. Total protein intake post-RT showed that protein quantity per EO and distribution could be further modified without introducing additional EO. Protein intake pre-RT and pre-bedtime was not an optimal practice among resistance-trained males. The results of this study suggest that the PEN approach advances traditional dietary assessment methods in the presence of dietary time-, training- and goal-specific recommendations. Furthermore, the PEN assessment may be considered as an advancement to traditional dietary assessment method that informs the understanding about the adequacy of nutrient intake patterns in proximity to an exercise session, in support of an individual’s intent.

5.9. Further Work
Further work that involves the PEN approach includes its application to other trained populations, with exercise programmes of different modalities and goals. Details of future work recommendations to improve the PEN assessment are discussed in detail in Chapter 10.
Chapter 6
Energy and Macronutrient Intake
Considerations in Support of Endurance Exercise Intent
6.1 List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>EA</td>
<td>Energy availability</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>ET</td>
<td>Endurance training</td>
</tr>
<tr>
<td>FFM</td>
<td>Fat-free mass</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RT</td>
<td>Resistance training</td>
</tr>
<tr>
<td>TEI</td>
<td>Total energy intake</td>
</tr>
<tr>
<td>VO(_{2})\text{max}</td>
<td>Maximal oxygen uptake</td>
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6.2. Abstract

This chapter provides an evidence-based literature review of energy availability and macronutrient intake strategies in support of fat loss, training adaptation and competitive performance when engaged with endurance exercise. The strategies of carbohydrate availability manipulation peri-exercise are summarised and indicate the timeframes for peri-exercise nutrition (PEN) analysis of the carbohydrate intake patterns that is used in the subsequent chapter.

6.3. Introduction

Adaptation to endurance exercise may be achieved via increased maximal oxygen uptake (VO\(_{2}\)\text{max}), number of mitochondria content or metabolic activity. Together, adaptation to endurance exercise allows sustaining the aerobic zone at higher training or competition intensities (Bartlett \textit{et al.} 2015; Radák 2018). Nutrient intake strategies may alter metabolic processes that support training adaptation and as a result, increase endurance performance. In endurance-based sports, carbohydrate intake has received the most attention. For example, carbohydrate periodisation may enhance metabolic processes that promote training adaptation, while high carbohydrate availability allows sustained training intensity during key endurance training (ET) sessions and competition events (Jeukendrup 2017; Burke \textit{et al.} 2018; Impey \textit{et al.} 2018). Moreover, acute (planned from hours to days) high carbohydrate intake strategies may improve endurance performance when tailored to a competitive endurance event (Burke \textit{et al.} 2011).

Cyclists’, runners’ and triathletes’ performance can be optimised by nutrient intakes in the days preceding a competitive event and on the day of the race. One of the
common methods is glycogen loading before an event (Burke et al. 2011) and high carbohydrate availability during the competition event (Stellingwerff and Cox 2014). Other than carbohydrate intake, other nutrients may aid muscle remodelling and repair (protein), provide energy (fat) or support an individual’s health (microelements) (Thomas et al. 2016). Furthermore, some dietary supplements (i.e. caffeine, nitrate) and appropriate hydration may improve an individual’s performance (Maughan et al. 2018).

This chapter offers an evidence-based review of daily and PEN energy and macronutrient intake strategies for endurance-trained individuals in support of fat loss, endurance training adaptation and endurance exercise performance. If there was no substantial evidence to suggest a prescription specific to exercise and one’s goals, no prescription was provided. The information presented in this chapter forms the basis for daily and PEN analysis of energy and macronutrient intakes specific to exercise and aims as reported by three, endurance-trained individuals. This analysis is offered in Chapter 7.

6.4. Dietary Considerations

Dietary considerations presented in this chapter relate to the case study provided in Chapter 7. Thus, it is not the aim of this chapter to discuss every possible dietary intake support of endurance training, but instead to investigate nutrient recommendations specific to exercise patterns and individuals’ aims examined in Chapter 7. The stated goals of three endurance-trained males recruited in this study were to improve performance and endurance. One subject aimed to concurrently reduce fat mass. The other two subjects competed in road cycling (60 km, 96 min) and running (8 km, 32 min) during the recording phase of this report.

6.4.1. Energy

Daily energy availability (EA) of \( \geq 45 \text{ kcal·kg}^{-1} \) of fat free mass (FFM) is recommended as optimal in support of physiological functions, training adaptation and sports performance (Loucks et al. 2011). Failure in optimising EA may result in an increased prevalence of illness (Drew et al. 2017) or alteration of the metabolic hormones (Geesmann et al. 2017) that may compromise individuals’ training goals and sports performance (Mountjoy et al. 2014). A hypocaloric energy availability of
30–45 kcal·kg\(^{-1}\) FFM·d\(^{-1}\) may be used periodically in support of fat mass loss during an exercise programme (Loucks \textit{et al.} 2011; Melin \textit{et al.} 2019).

6.4.2. Protein

Protein intake recommendations in the presence of ET aim to restore the net protein balance due to protein oxidation during exercise (Phillips \textit{et al.} 2007). Different from RT, protein intake during ET increases mitochondrial not myofibrillar protein synthesis (Holloszy and Coyle 1984). Daily recommended protein intake for athletes is 1.2–2.0 g·kg\(^{-1}\)·d\(^{-1}\) (Thomas \textit{et al.} 2016). Protein intake requirements specific to ET might be closer to 1.5–1.8 g·kg\(^{-1}\)·d\(^{-1}\) (Brouns \textit{et al.} 1989b; Brouns \textit{et al.} 1989a; Kato \textit{et al.} 2016). Additionally, Kato \textit{et al.} (2016) suggest that further research is warranted to identify if the estimated protein intake of 1.65–1.83 g·kg\(^{-1}\)·d\(^{-1}\) is optimal while performing ET. The proposed recommendations fall within ~10–15% of total energy intake (TEI) from protein for individuals engaged in endurance programmes (Tarnopolsky 2004). Additionally, protein intake in an energy deficient diet (e.g. EA of 30–45 kcal·kg\(^{-1}\) FFM·d\(^{-1}\) as discussed above) is recommended at 1.6–2.4 g·kg\(^{-1}\)·d\(^{-1}\) to maintain or gain muscle mass (Hector and Phillips 2018). Since consensus has not been reached on the optimal daily protein intake for ET, general dietary recommendations (i.e. 1.2–2.0 g·kg\(^{-1}\)·d\(^{-1}\)) were used in the analysis of protein intake of endurance-trained individuals who did not report the aim of fat mass loss (Thomas \textit{et al.} 2016). When one subject aimed for muscle hypertrophy and strength gain, the recommended protein value for the day was set as 1.6–2.2 g·kg\(^{-1}\)·d\(^{-1}\) (Maughan \textit{et al.} 2018).

Rapidly digested, a high quality protein of 0.3 g·kg\(^{-1}\)·EO\(^{-1}\) (20–25 g·EO\(^{-1}\)) is recommended within the first hour after ET and competition in support of muscle repair and remodelling (Moore \textit{et al.} 2014). When carbohydrate intake is limited (< 1.2 g·kg\(^{-1}\)·EO\(^{-1}\)), co-ingestion of protein (i.e. 0.3–0.4 g·kg\(^{-1}\)·EO\(^{-1}\)) immediately after endurance exercise and again at two hours (Ivy \textit{et al.} 2002) or at 30-minute time intervals (Alghannam \textit{et al.} 2016) is recommended in the first four hours post-exercise to enhance glycogen resynthesis. The suboptimal intake of carbohydrate (i.e. 0.8 g·kg\(^{-1}\)·h\(^{-1}\)) consumed with protein within the first four hours post-endurance exercise results in a greater glycogen resynthesis rate than carbohydrate intake alone (van Loon \textit{et al.} 2000; Ivy \textit{et al.} 2002; Williams \textit{et al.} 2003; Betts and Williams 2010; Alghannam \textit{et al.} 2016). No superior effect on glycogen resynthesis was observed after co-ingestion.
of protein with $\geq 1.2 \text{ g kg}^{-1}\cdot\text{EO}^{-1}$ of carbohydrate in comparison to 1.2 g kg$^{-1}\cdot$EO$^{-1}$ of carbohydrate consumed alone (van Hall *et al.* 2000; Jentjens *et al.* 2001). Additionally, protein sources of higher digestibility such as whey protein, in comparison to casein (Reitelseder *et al.* 2011) or liquid forms over solid forms (Burke *et al.* 2012b) are recommended to enhance the insulinotrop effect of protein.

6.4.3. Carbohydrate

Carbohydrate intake recommendations for endurance training sessions and competition events have been studied extensively. As a result, daily guidelines are summarised according to exercise session duration and intensity (Burke *et al.* 2011) in Table 23. Further optimisation of daily carbohydrate intake requirements might be feasible if the energy expenditure values, an individual’s intent and body composition characteristics are known.

Table 23 Guidelines for daily carbohydrate intake, adapted from Burke *et al.* (2011)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Carbohydrate requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-intensity or skill-based activities</td>
<td>3–5 g kg$^{-1}\cdot$d$^{-1}$</td>
</tr>
<tr>
<td>Moderate exercise programme (i.e. ~1 h $\cdot$ d$^{-1}$)</td>
<td>5–7 g kg$^{-1}\cdot$d$^{-1}$</td>
</tr>
<tr>
<td>Endurance programme (e.g. moderate-to-high intensity exercise of 1–3 h $\cdot$ d$^{-1}$)</td>
<td>6–10 g kg$^{-1}\cdot$d$^{-1}$</td>
</tr>
<tr>
<td>Extreme commitment (i.e. moderate-to-high intensity exercise of &gt; 4–5 h $\cdot$ d$^{-1}$)</td>
<td>8–12 g kg$^{-1}\cdot$d$^{-1}$</td>
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</table>

*Note. Data are expressed per kilogram of body mass per day.*

The carbohydrate intake periodisation includes pre-, during- and post-endurance exercise carbohydrate provisions to support training adaptation (Jeukendrup 2017) and exercise performance (Burke *et al.* 2011). However, the contemporary approach considers carbohydrate periodisation within time frameworks rather than the exact quantity and time of recommended intake peri-endurance exercise (Burke *et al.* 2018; Impey *et al.* 2018). Strategies of carbohydrate availability periodisation, i.e. “train low” and “train high” approaches are summarised in Table 24.

6.4.3.1. Key Sessions and Competition Events

Generally, key endurance training sessions of high intensity and competitive events are conducted with high carbohydrate availability (before and during exercise) in
support of optimal performance (Bartlett et al. 2015). Recommended carbohydrate intakes, to achieve high carbohydrate availability, are 7–12 g kg\(^{-1}\)·24h\(^{-1}\) for endurance exercise of < 90 minutes duration or 10–12 g kg\(^{-1}\)·24h\(^{-1}\) for 36–48 hours pre-exercise for endurance exercise of > 90 minutes duration. The acute fuelling strategies 1–4 hours before an event include intake of 1–4 g kg\(^{-1}\) of carbohydrate (Burke et al. 2011). Anticipated glycogen depletion in endurance exercise lasting less than an hour should not limit sports performance. An adequately pre-fuelled trained individual should not require carbohydrate intake during an endurance session of less than 60 minutes duration. (Jeukendrup and Chambers 2010; Jeukendrup 2014; Stellingwerff and Cox 2014). In key training sessions or competition events of shorter duration (i.e. 30–70 minutes), carbohydrate mouth rinse was shown to improve performance. For example, Chambers et al. (2009) showed that mouth rinse with 25 ml of ~6% glucose solution, consumed every 10 min during an hour of cycling training at 75% VO\(_2\)max resulted in 2% improvement (~1.2 min) in comparison to saccharin consumption. Alternatively, carbohydrate intake of 30–60 g h\(^{-1}\) is recommended for exercise lasting between one hour and 2.5–3 hours (Burke et al. 2011; Jeukendrup 2014). General guidelines recommend carbohydrate intake of 1.0–1.2 g kg\(^{-1}\)·h\(^{-1}\) for four hours for rapid glycogen resynthesis in time restricted recovery (i.e. < 8 hours) (Burke et al. 2011). However, the application of rapid glycogen refuelling strategies post-exercise depends on the recovery time and proximity to the next training or competition session. In the absence of these sessions, the daily adequate carbohydrate intake may be distributed according to individual preferences (Burke et al. 2017b).

### 6.4.3.2. Fuelling to Support Adaptation to ET and Fat Loss

In endurance exercise sessions, reduced carbohydrate intake enhances fat oxidation, acute cell-signalling pathways, oxidative skeletal muscle adaptation and may improve sports performance (Burke et al. 2018; Impey et al. 2018). Thus, it is recommended to perform 30–50% of endurance training sessions in a low carbohydrate state (Impey et al. 2018). However, there is no single carbohydrate intake prescription to support adaptation to ET (Burke et al. 2018) and the optimal carbohydrate intake values within the periodised strategies have not been established (Impey et al. 2018). Periodised nutrition engages in offering practical solutions in line with the training goals of an individual, rather than proposing a one-size-fits-all approach (Stellingwerff et al. 2007; Stellingwerff et al. 2011; Jeukendrup 2017; Burke et al. 2018; Stellingwerff et
al. 2019). Hence, in the subsequent chapter, the patterns rather than adequacy of carbohydrate intake are analysed. Table 24 presents a summary of carbohydrate intake periodisation strategies adapted from reviews of research by Impey et al. (2018) and Burke et al. (2018) that underpin fat loss, enhance training adaptation, and lead to greater sports performance.

Table 24 Carbohydrate intake periodisation strategies adapted from Burke et al. (2018) and Impey et al. (2018)

<table>
<thead>
<tr>
<th>Carbohydrate availability</th>
<th>Strategy summary</th>
</tr>
</thead>
</table>
| Low                       | - Low glycogen–training session performed with lower glycogen stores (i.e. second training of the day);  
                          | - Recover low/sleep low–delayed carbohydrate intake that results in delayed muscle glycogen resynthesis post-training, in the morning (i.e. recover low) or in the evening (i.e. sleep low);  
                          | - Train low or overnight fast–low exogenous carbohydrate intake, i.e. training in a fasted state (overnight fast) or no carbohydrate intake for at least six hours pre-training session and no carbohydrate intake during a training session. |
| High                      | - Carbohydrate loading–carbohydrate intake of 10–12 g·kg⁻¹·24h⁻¹ for 36–48 hours before the endurance event;  
                          | - High exogenous carbohydrate intake–carbohydrate intake during an exercise, according to recommendations, e.g. 30–60 g·h⁻¹ of carbohydrate during exercise of 1–2.5 hours duration;  
                          | - High glycogen exercise session–commence an exercise session with an optimal level of glycogen to meet the demands of exercise. The strategy requires daily moderate to high carbohydrate intake of 5–12 g·kg⁻¹·d⁻¹;  
                          | - Pre-session fuelling–carbohydrate intake of 1–4 g·kg⁻¹ for 1–4 hours pre-exercise to restore either liver or muscle glycogen;  
                          | - Recover high–carbohydrate intake of 1–1.2 g·kg⁻¹·h⁻¹ for the first four hours post-exercise. |

*Note. EO–Eating occasion.*
6.4.4. Fat

Fat intake recommendations for the general adult population and adopted for athletic populations range between 20% and 35% of TEI (Manore 2005; Thomas et al. 2016). Generally, fat intake above 20% of TEI from fat supports the intake of monounsaturated and polyunsaturated fatty acids (Smith et al. 2011). Furthermore, 25–30% of TEI from fat is recommended to promote fat loss over very low fat intake of 10–20% of TEI (Aragon et al. 2017).

6.5 Conclusions

The evidence presented in this chapter serves to inform traditional and PEN analysis tailored to stated intent and reported exercise programme as found in Chapter 7. Daily energy and macronutrient recommendations for endurance-trained individuals in support of endurance performance are well described in the extant literature. Carbohydrate intake periodisation offers opportunities to advance daily carbohydrate intake strategies to enhance endurance training adaptation and exercise performance (Burke and Hawley 2018). Evidence has demonstrated that restricted carbohydrate intake for 30–50% of ET sessions improves skeletal muscle adaptation (Impey et al. 2018). Since there is no one recommended strategy of carbohydrate periodisation, the patterns of carbohydrate intake within a periodised approach should be tailored to a trained individual’s exercise patterns and intent.
Chapter 7
Case Study: Assessment of Energy and Macronutrient Intakes of Three Endurance-Trained Individuals Using Traditional and Peri-Exercise Nutrition Methods of Analysis
7.1. List of Abbreviations

CD  Competition day/s
EA  Energy availability
EEE Exercise energy expenditure
EO  Eating occasion/s
ET  Endurance training
FFM Fat-free mass
N/A Not applicable
PEN Peri-exercise nutrition
RD  Rest day/s
RPE Rating of Perceived Exertion
RT  Resistance training
SD  Standard deviation
TEI Total energy intake
TD  Training day/s
VO\textsubscript{2}max Maximal oxygen uptake

7.2. Abstract

In endurance sports, the effects of carbohydrate intake have been studied most extensively, demonstrating that daily and peri-endurance exercise carbohydrate intake strategies can augment the intended outcomes of endurance exercise (Burke et al. 2011; Impey et al. 2018). This chapter presents, in case-study format, the dietary assessment of energy and macronutrient intakes specific to endurance training (ET) and competition of three endurance-trained males. In addition to a 7-day dietary intake record, subjects provided data for seven days of endurance-based exercise training and competition sessions, which were designed to promote endurance adaptation, performance, and also fat mass loss. Daily, and in proximity to exercise, energy and macronutrient intake data were subjected to traditional dietary and peri-exercise nutrition (PEN) analysis. According to the aims of this chapter, the example of a decision process of PEN analysis for the multiple training session sequence was demonstrated. The literature-informed evidence of recommended energy and macronutrient intakes formed the basis of dietary analysis. According to traditional analysis of daily adequate energy and macronutrient intakes for seven days, energy availability (EA) and/or macronutrient intakes were adequate on 0–4 days. The PEN
analysis revealed that greater carbohydrate intake restriction pre-ET was achieved by one subject who aimed for fat mass loss on multiple occasions, but he also did not meet daily EA and carbohydrate intake requirements. Carbohydrate was recorded within the recommended intake for a competition event of 96 minutes duration, four hours pre- and during session for one subject. Results of this study suggest that daily energy and nutrient intakes and PEN carbohydrate intake requires goal-orientated refinement. In conclusion, this case study demonstrates that the PEN approach reveals the nuances of carbohydrate intake practices peri–endurance exercise within the daily energy and macronutrient intake patterns.

7.3. Introduction
Chronic, high carbohydrate intake is not the sole nutrition strategy to augment endurance exercise adaptation and performance. Trained and athletic populations can benefit from peri-ET carbohydrate periodisation (Burke et al. 2018; Impey et al. 2018). Daily assessment of dietary intake of endurance athletes has been reported comprehensively in the literature (Burke et al. 2003; Erdman et al. 2013), but does not identify if athletes optimise the within-day patterns of nutrient intakes. Yet, the analyses of nutrient intake pre-, during and post-endurance exercise have been conducted mainly in proximity to competition (Stellingwerf 2012; Carr et al. 2019; Heikura et al. 2019). Less attention has been given to evaluate the adequacy of peri-ET nutrient intake (Burke et al. 2003), though implementation of guidelines for carbohydrate periodisation, and time-specific intake has been examined with an online survey of elite endurance athletes (Heikura et al. 2017; Heikura et al. 2018a). The research study presented in this chapter provides a case study approach of the quantitative traditional and PEN-based analysis of the energy and macronutrient intakes of three endurance-trained males. The evidence-based energy and macronutrient intake recommendations in support of endurance training and competition, and an individual’s intent, are documented in Chapter 6.

7.4. Aim
This case study of a 7-day microcycle of training and competition undertook traditional and PEN methods of dietary assessment to examine the patterns and/or adequacy of energy and macronutrient intakes in support of the endurance exercise intent of three endurance-trained males.
The objectives to fulfil this aim were:

1. Traditional method of dietary assessment
   - To examine the patterns and adequacy of total energy and macronutrient intakes in comparison to daily recommended values (see Chapter 6) for training, rest and competition days

2. PEN method of dietary assessment
   - To analyse the patterns of peri-ET carbohydrate intake for single and multiple daily training sessions
   - To examine the patterns and adequacy of high carbohydrate availability within 48 hours pre-, four hours pre-, during and four hours post-endurance competition events, and to evaluate protein intake within four hours post-endurance exercise when carbohydrate intake per EO was suboptimal (see Chapter 6)
   - To examine the pattern and adequacy of protein intake and to examine the quantity of carbohydrate co-ingestion with suboptimal protein intake peri-resistance training (RT) in support of training adaptation reported, according to the scientific literature reviewed in Chapter 4
   - To demonstrate the example of the PEN analysis of multiple sessions reported in a day.

7.5. Methods
The inclusion criteria for participants recruited in this study are described in Chapter 3, Section 3.4. The general information about methodology and methods used for data collection, entry and data analysis are presented in Chapter 3, Section 3.5–3.10. Data of each endurance-trained male subject were reported and analysed individually. The evidence-based recommended energy and macronutrient intakes specific to endurance exercise and in support of the intent reported by individuals recruited to this study individuals is summarised in Chapter 6. Carbohydrate and protein intake was analysed according to the PEN phases as described in section 7.5.1.

7.5.1. PEN Analysis Specific to ET
Carbohydrate and protein intake was analysed in the PEN phases outlined in Table 25. The duration of identified phases was derived according to the terminology provided
by Burke et al. (2018) and Impey et al. (2018), and summarized in Chapter 6, Section 6.4.3.2 for the PEN analysis of three endurance-trained males.

Table 25 Temporal patterns of carbohydrate and protein intake analysis peri-endurance exercise

<table>
<thead>
<tr>
<th>PEN phases</th>
<th>Nutrient</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six hours pre-ET</td>
<td>Carbohydrate</td>
<td>All EO consumed within ≤ 6-hours pre-ET and up to the recorded start-time of an ET session (exclusive). If more than one ET was performed within one day, only the first ET that day was included in this analysis.</td>
</tr>
<tr>
<td>Between two ET</td>
<td></td>
<td>All EO consumed between two recorded ET sessions within the same day. The nutrient intake was evaluated between end-time of the first ET session (inclusive) and the recorded start-time of the next ET training session (exclusive).</td>
</tr>
<tr>
<td>Post-ET up to the recorded bedtime</td>
<td></td>
<td>All EO consumed between the recorded end-time of ET (inclusive) and recorded bedtime (exclusive). The data were analysed for the last ET session of the day. If only one ET was reported within a day, this analysis was not conducted.</td>
</tr>
<tr>
<td>48 hours pre-endurance competition</td>
<td></td>
<td>All EO consumed within ≤ 48-hours pre-endurance competition event, up to the recorded time of the beginning of an event (exclusive). The analysis is performed for an endurance competition event of &gt; 90 minutes duration.</td>
</tr>
<tr>
<td>4 hours pre-endurance competition</td>
<td></td>
<td>All EO consumed within ≤ 4-hours pre-endurance competition event, up to the recorded time of the beginning of an event (exclusive).</td>
</tr>
<tr>
<td>During-ET and endurance competition event</td>
<td></td>
<td>All EO consumed between the recorded start-time of ET and endurance competition event (inclusive) and the recorded end-time of the same event (exclusive).</td>
</tr>
<tr>
<td>4 hours post-endurance competition</td>
<td>Carbohydrate and protein</td>
<td>All EO consumed between the recorded end-time of endurance competition (inclusive) and up to four hours post-competition (inclusive).</td>
</tr>
</tbody>
</table>

Note. EO–Eating occasion/s; PEN–Peri-exercise nutrition; ET–Endurance training.
7.6. Results

7.6.1. Participants

Table 26 provides the anthropometric profile of case study subjects.

Table 26 Anthropometric profile of endurance-trained subjects

<table>
<thead>
<tr>
<th></th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>31.9</td>
<td>41.5</td>
<td>22.5</td>
<td>32.0 (9.5)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181.3</td>
<td>165.5</td>
<td>191.5</td>
<td>179.4 (13.1)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>66.8</td>
<td>60.4</td>
<td>85.2</td>
<td>70.8 (12.9)</td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>58.4</td>
<td>51.5</td>
<td>71.1</td>
<td>60.3 (9.9)</td>
</tr>
<tr>
<td>Lean tissue mass (kg)</td>
<td>55.6</td>
<td>48.4</td>
<td>67.7</td>
<td>57.2 (9.8)</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>13.8</td>
<td>15.7</td>
<td>14.0</td>
<td>15.6 (1.7)</td>
</tr>
<tr>
<td>VO\textsubscript{2}max (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>72.4</td>
<td>61.1</td>
<td>66.9</td>
<td>66.8 (5.7)</td>
</tr>
</tbody>
</table>

Note. SD–Standard deviation; VO\textsubscript{2}max–Maximal oxygen uptake.

7.6.2. Exercise Programme

Table 27 summarises the exercise programmes reported by participants. Detailed information about training sessions and competition events are provided in Table 28, Table 29 and Table 30 for each subject.

Table 27 Characteristics of subjects’ 7-day exercise and non-exercise activities

<table>
<thead>
<tr>
<th>Sports discipline</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase of season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of TD weekly</td>
<td>3</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Number of RD weekly</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of CD weekly</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Number of endurance exercise sessions weekly</td>
<td>6</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Number of training sessions weekly, other than endurance exercise</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Mean (SD) duration of an endurance exercise session (hh:mm)</td>
<td>01:00 (00:18)</td>
<td>00:56 (00:33)</td>
<td>01:04 (00:11)</td>
</tr>
<tr>
<td>Mean (SD) duration of an exercise session, other than endurance (hh:mm)</td>
<td>N/A</td>
<td>N/A</td>
<td>00:45 (00:00)</td>
</tr>
</tbody>
</table>

Note. CD–Competition days; N/A–Not applicable; RD–Rest days; SD–Standard deviation; TD–Training days.
Table 28 Exercise programme reported by Subject 1

<table>
<thead>
<tr>
<th>Number, type of day</th>
<th>Characteristics of training sessions and competition events</th>
<th>Start time (hh:mm), duration (min)</th>
<th>Stated intent</th>
<th>EEE (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 2, TD</td>
<td>Morning cycle (steady-state, RPE 4)</td>
<td>7:17, 50</td>
<td>Improve performance and VO(_2) max</td>
<td>517</td>
</tr>
<tr>
<td></td>
<td>Afternoon cycle (steady-state, RPE 5)</td>
<td>16:50, 52</td>
<td>Improve performance and VO(_2) max</td>
<td>619</td>
</tr>
<tr>
<td>Day 3, TD</td>
<td>Morning cycle (steady-state, RPE 5)</td>
<td>07:20, 51</td>
<td>Improve performance and VO(_2) max</td>
<td>522</td>
</tr>
<tr>
<td></td>
<td>Afternoon cycle (steady-state, RPE 5)</td>
<td>17:50, 51</td>
<td>Improve performance and VO(_2) max</td>
<td>534</td>
</tr>
<tr>
<td>Day 5, TD</td>
<td>Evening cycle (includes intervals, RPE 2)</td>
<td>20:08, 60</td>
<td>Improve endurance, train on different intensities</td>
<td>221</td>
</tr>
<tr>
<td>Day 7, CD</td>
<td>Race 60 km cycle (RPE 5)</td>
<td>12:45, 96</td>
<td>To win</td>
<td>956</td>
</tr>
</tbody>
</table>

*Note. EEE—Exercise energy expenditure; CD—Competition Day; RPE—Rating of Perceived Exertion, 0–10 Borg’s scale (Borg 1982), TD—Training day.*
<table>
<thead>
<tr>
<th>Number, type of day</th>
<th>Characteristics of training sessions and competition events</th>
<th>Start time (hh:mm), duration (min)</th>
<th>Stated intent</th>
<th>EEE (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1, TD</td>
<td>Morning swim (includes intervals, RPE 4)</td>
<td>08:10, 45</td>
<td>Improve endurance</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>Afternoon cycle (steady-state, RPE 4)</td>
<td>17:00, 62</td>
<td>Improve endurance</td>
<td>661</td>
</tr>
<tr>
<td>Day 2, TD</td>
<td>Evening run (includes intervals, RPE 6)</td>
<td>19:10, 60</td>
<td>Improve performance</td>
<td>403</td>
</tr>
<tr>
<td>Day 3, TD</td>
<td>Morning swim (includes intervals, RPE 4)</td>
<td>08:20, 25</td>
<td>Improve endurance</td>
<td>119</td>
</tr>
<tr>
<td>Day 4, TD</td>
<td>Noon swim (includes intervals, RPE 4)</td>
<td>13:15, 45</td>
<td>Improve endurance</td>
<td>214</td>
</tr>
<tr>
<td>Day 6, TD</td>
<td>Morning cycle (steady-state, RPE 5)</td>
<td>08:30, 125</td>
<td>Improve endurance</td>
<td>1374</td>
</tr>
<tr>
<td>Day 7, CD</td>
<td>Race 8 km run (RPE 7)</td>
<td>13:00, 32</td>
<td>Improve endurance, preparation for the next season</td>
<td>378</td>
</tr>
</tbody>
</table>

*Note. EEE—Exercise energy expenditure; CD—Competition Day; RPE—Rating of Perceived Exertion, 0–10 Borg’s scale (Borg 1982), TD—Training day.*
<table>
<thead>
<tr>
<th>Number, type of day</th>
<th>Characteristics of training sessions and competition events</th>
<th>Start time (hh:mm), duration (min)</th>
<th>Stated intent</th>
<th>EEE (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1, TD</td>
<td>Morning swim (steady-state, RPE 3)</td>
<td>07:30, 75</td>
<td>Improve endurance, performance, work on technique</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Afternoon run (steady-state, RPE 2)</td>
<td>18:00, 65</td>
<td>Improve endurance, performance, lose fat mass</td>
<td>689</td>
</tr>
<tr>
<td>Day 2, TD</td>
<td>Noon run (steady-state, RPE 2)</td>
<td>12:30, 50</td>
<td>Improve endurance, performance, work on technique</td>
<td>592</td>
</tr>
<tr>
<td></td>
<td>Evening run (steady-state, RPE 2)</td>
<td>18:45, 60</td>
<td>Improve endurance, performance, lose fat mass</td>
<td>749</td>
</tr>
<tr>
<td>Day 3, TD</td>
<td>Morning swim (steady-state, RPE 3)</td>
<td>07:30, 75</td>
<td>Improve endurance, performance, work on technique</td>
<td>514</td>
</tr>
<tr>
<td></td>
<td>Morning resistance training (RT, RPE 6)</td>
<td>09:00, 45</td>
<td>Improve performance, strength, muscle hypertrophy</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>Afternoon run (includes intervals, RPE 5)</td>
<td>18:00, 60</td>
<td>Improve performance, endurance, work different intensities</td>
<td>299</td>
</tr>
<tr>
<td>Day 4, TD</td>
<td>Morning swim (steady-state, RPE 3)</td>
<td>07:30, 75</td>
<td>Improve endurance, performance</td>
<td>514</td>
</tr>
<tr>
<td></td>
<td>Afternoon run (steady-state, RPE 2)</td>
<td>18:00, 45</td>
<td>Improve endurance, performance, lose fat mass</td>
<td>463</td>
</tr>
<tr>
<td>Day 5, TD</td>
<td>Morning RT (no RPE provided)</td>
<td>09:00, 45</td>
<td>-</td>
<td>257</td>
</tr>
<tr>
<td>Day 7, TD</td>
<td>Evening run (steady-state, RPE 2)</td>
<td>18:00, 70</td>
<td>Improve endurance, performance, lose fat mass</td>
<td>1046</td>
</tr>
</tbody>
</table>

Note. EEE–Exercise energy expenditure; RPE–Rating of Perceived Exertion, 0–10 Borg’s scale (Borg 1982), TD–Training day.
7.6.3. Traditional Dietary Analysis

Mean daily energy and macronutrient intakes for 7 days, TD, RD and CD were reported for each case study and analysed by comparison to the recommended intake (Table 31). The values that lay within the recommended range were classified as those that met daily dietary recommendations. If subjects did not meet EA, the reported values were < 45 kcal·kg FFM$^{-1}$·d$^{-1}$ for Subjects 1–3, and < 30 kcal·kg FFM$^{-1}$·d$^{-1}$ for Subject 3 on days when he aimed for fat loss. Subject 1 and Subject 2 exceeded the recommended 2.0 g·kg$^{-1}$·d$^{-1}$ of protein if protein intake was not reported within the recommended ranges, except for Subject 2, who did not meet 1.2 g·kg$^{-1}$·d$^{-1}$ of protein on CD. Subject 3 did not meet the lower recommended daily protein intake if protein intake did not lie within the recommendations. According to reported carbohydrate intake that did not lie within the recommended ranges, Subject 1 exceeded recommended 7 g·kg$^{-1}$·d$^{-1}$ of carbohydrate on one RD but did not meet the lower recommended value for carbohydrate intake on two TD and the CD. Subject 2 did not meet lower recommended carbohydrate intake on three TD, and Subject 3 did not on all 7 days of recording. When participants’ fat intake was not reported within the recommended values, subjects exceeded recommended fat intake expressed as a percentage of total energy intake (TEI) (see Table 31).
Table 31 Daily energy and macronutrient intakes of subjects

<table>
<thead>
<tr>
<th></th>
<th>Energy and macronutrient intakes</th>
<th>Daily dietary intake</th>
<th>Daily recommendations</th>
<th>Adequacy of daily dietary intake (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 days</td>
<td>TD</td>
<td>RD</td>
<td>CD</td>
<td>TD</td>
</tr>
<tr>
<td>Energy (kcal·kg⁻¹·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>53 (7)</td>
<td>50 (5)</td>
<td>60 (5)</td>
<td>47</td>
<td>45</td>
</tr>
<tr>
<td>Subject 2</td>
<td>45 (7)</td>
<td>47 (8)</td>
<td>44</td>
<td>41</td>
<td>45</td>
</tr>
<tr>
<td>Subject 3</td>
<td>30 (9)</td>
<td>31 (9)</td>
<td>20</td>
<td>-</td>
<td>30–45</td>
</tr>
<tr>
<td>Energy availability (kcal·kg FFM⁻¹·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>53 (16)</td>
<td>43 (12)</td>
<td>68 (6)</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>Subject 2</td>
<td>44 (9)</td>
<td>43 (10)</td>
<td>51</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Subject 3</td>
<td>23 (18–24)</td>
<td>24 (10)</td>
<td>24</td>
<td>-</td>
<td>30–45</td>
</tr>
<tr>
<td>Protein (g·kg⁻¹·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>2.7 (0.6)</td>
<td>2.5 (0.6)</td>
<td>3.0 (0.8)</td>
<td>2.4</td>
<td>1.2–2.0</td>
</tr>
<tr>
<td>Subject 2</td>
<td>1.7 (0.4)</td>
<td>1.8 (0.3)</td>
<td>1.8</td>
<td>1.1</td>
<td>1.2–2.0</td>
</tr>
<tr>
<td>Subject 3</td>
<td>1.1 (0.4)</td>
<td>1.2 (0.3)</td>
<td>0.5</td>
<td>-</td>
<td>1.6–2.4²</td>
</tr>
<tr>
<td>Carbohydrate (g·kg⁻¹·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>6.1 (1.1)</td>
<td>6.1 (1.1–)</td>
<td>6.3 (1.7)</td>
<td>4.9</td>
<td>6–9</td>
</tr>
<tr>
<td>Subject 2</td>
<td>5.0 (1.2)</td>
<td>4.9 (1.4)</td>
<td>5.2</td>
<td>5.6</td>
<td>6–8</td>
</tr>
<tr>
<td>Subject 3</td>
<td>3.2 (0.9)</td>
<td>3.3 (0.9)</td>
<td>2.2</td>
<td>-</td>
<td>4–8</td>
</tr>
</tbody>
</table>

1 Adequacy of daily dietary intake (%)
2 N = 2
3 N = 0
<table>
<thead>
<tr>
<th>Energy and macronutrient intakes</th>
<th>Daily dietary intake 7 days</th>
<th>Daily recommendations</th>
<th>Adequacy of daily dietary intake (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
<td>RD</td>
<td>CD</td>
<td>TD</td>
</tr>
<tr>
<td>Fat (g·kg⁻¹·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>2.0 (0.5)</td>
<td>1.7 (1.4)</td>
<td>2.5 (0.1)</td>
<td>1.9</td>
</tr>
<tr>
<td>Subject 2</td>
<td>1.9 (0.6)</td>
<td>2.0 (0.5)</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Subject 3</td>
<td>1.4 (0.6)</td>
<td>1.4 (0.6)</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>Fat (% TEI·d⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>34 (5)</td>
<td>29 (1)</td>
<td>38 (2)</td>
<td>37</td>
</tr>
<tr>
<td>Subject 2</td>
<td>37 (9)</td>
<td>40 (8)</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>Subject 3</td>
<td>41 (7)</td>
<td>40 (8)</td>
<td>47</td>
<td>-</td>
</tr>
</tbody>
</table>

Note. Data are means (SD) for reported daily dietary intake, except for EA for 7 days reported by Subject 3 and carbohydrate and fat intake reported on TD by Subject 1 where data are medians (25th–75th percentiles). ¹Daily ranges of recommended intake are provided according to Manore (2005), Loucks et al. (2011), Thomas et al. (2016) and Burke et al. (2011). ²Protein intake of 1.2–2.0 g·kg⁻¹·d⁻¹ and fat intake of 20–35% of TEI were considered adequate when the subject did not aim for fat loss. ³Carbohydrate intake requirements were calculated to meet EA of 45 kcal·kg FFM⁻¹·d⁻¹ for subjects, and 30–45 kcal·kg FFM⁻¹·d⁻¹ for Subject 3 when he aimed for fat loss. Provided ranges considered the minimal and maximal protein and fat intake recommendations for each subject. CD—Competition day/s; EA—Energy availability; FFM—Fat-free mass; N/A—Not applicable; RD—Rest day/s; TD—Training day/s; TEI—Total energy intake.
7.6.4. PEN Analysis for Endurance Exercise

According to the PEN assessment’s first objective, to investigate the patterns of carbohydrate availability peri-ET, Table 32 provides results of carbohydrate intake six hours before the first ET sessions of a day, between two ET the same day, and after the last (in this study, the second) ET session of a day. The same table provides a mean (SD) of carbohydrate intake for each subject within the identified phases. According to the reported data, only Subject 3 did not consume carbohydrate within 6 hours before 40% of first ET sessions of a day ($N = 5$). During ET sessions, Subject 1 and 3 did not report EO. Subject 2 consumed 0.3 g·kg$^{-1}$ of carbohydrate during ET on Day 4 and 1.0 g·kg$^{-1}$ on Day 6.

Table 32 Carbohydrate intake peri-ET

<table>
<thead>
<tr>
<th>Carbohydrate intake peri-ET (g·kg$^{-1}$)</th>
<th>6 hours pre-ET</th>
<th>Between two ET</th>
<th>Post-ET up to the recorded bedtime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subject 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>0.4</td>
<td>3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Day 3</td>
<td>0.3</td>
<td>3.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Day 5</td>
<td>1.0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Mean (SD)</strong></td>
<td>0.6 (0.4)</td>
<td>3.3 (0.4)</td>
<td>2.8 (0.2)</td>
</tr>
<tr>
<td><strong>Subject 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>1.8</td>
<td>2.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Day 2</td>
<td>2.3</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Day 3</td>
<td>0.6</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Day 4</td>
<td>2.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Day 6</td>
<td>1.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Mean (SD)</strong></td>
<td>2.1 (0.9)</td>
<td>2.7</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Subject 3</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>0.1</td>
<td>0.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Day 2</td>
<td>0.9</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Day 3</td>
<td>0</td>
<td>3.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Day 4</td>
<td>0</td>
<td>2.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Day 7</td>
<td>1.4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Mean (SD)</strong></td>
<td>0.5 (0.7)</td>
<td>1.7 (1.0)</td>
<td>1.7 (1.0)</td>
</tr>
</tbody>
</table>

Note. ET—Endurance training; N/A—Not applicable, only one ET was reported that day.
The PEN analysis of patterns and adequacy of carbohydrate availability within four hours pre-, during and four hours post-endurance competition event are provided in Table 33. Protein intake within four hours post-endurance exercise and number of EO are presented in the same table as carbohydrate intake. Subject 3 was not included in the carbohydrate and protein intake analysis peri-endurance competition, since he did not compete during the data recording phase.

Table 33 Carbohydrate and protein intake peri-endurance competitive event

<table>
<thead>
<tr>
<th></th>
<th>4 hours pre-endurance competition</th>
<th>During-endurance competition</th>
<th>4 hours post-endurance competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbohydrate (g·kg⁻¹)</td>
<td>Protein (g·kg⁻¹)</td>
<td>Number of EO</td>
</tr>
<tr>
<td><strong>Subject 1</strong></td>
<td><strong>Day 7</strong></td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Subject 2</strong></td>
<td><strong>Day 7</strong></td>
<td>3.2</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note. EO—Eating occasion.*

Subject 1 met recommended carbohydrate intake four hours before and during the competitive event of 96 minutes duration. Subject 2 commenced the race with the recommended carbohydrate intake. Subject 2, unlike Subject 1, reported carbohydrate and protein intake within the first four hours post-race. Subject 1 consumed 7.5 g·kg⁻¹·24h⁻¹ of carbohydrate within 48 hours of recommended carbohydrate loading before the race of > 90 minutes duration (i.e. 7 g·kg⁻¹·24h⁻¹ within 48–24 hours and 8.1 g·kg⁻¹·24h⁻¹ within 24–0 hours pre-race).

7.6.5. PEN Analysis for RT

Subject 3 reported two RT sessions. However, due to incomplete data for one of them (see Table 30), the data were excluded from analysis. The aim of the RT session included in the PEN analysis was to support subject’s sports performance, muscle hypertrophy and gain in strength. The PEN prescription tailored for muscle hypertrophy and gain in strength is provided in Chapter 4. As specified in Table 13, protein and carbohydrate intake pre- during and post-RT was included in the PEN analysis. No EO was reported an hour before and during an RT session. Subject 3 reported five EO distributed 03:23 (02:18) hh:mm in 24-hour post-RT phase. The recommended protein distribution of 3–5 hours was achieved in 67% instances of EO
distribution ($N = 3$). Within the 24 hours post-RT, Subject 3 consumed $1.6 \text{ g} \cdot \text{kg}^{-1} \cdot 24\text{h}^{-1}$ of protein. The first EO post-RT was consumed 00:05 hh:mm post-RT and provided $0.2 \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$ of protein. The second EO post-RT was consumed at 04:30 hh:mm and provided $0.4 \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$ of protein. Subject 3 reported one EO that provided $0.9 \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$ of protein. However, protein intake below $0.3 \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$ was reported on three EO (i.e. $0.2 \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$) with average carbohydrate co-ingestion of $0.7 (0.3) \text{ g} \cdot \text{kg}^{-1} \cdot \text{EO}^{-1}$. Subject 3 slept 06:40 hh:mm within the 24-hour post-RT phase and did not report EO within the last hour before bedtime.

7.6.6. An Example of the PEN Analysis Decision Process for One Day With Multiple Training Sessions

Subject 3 reported three training sessions on Day 3. The aims of ET sessions were to support adaptation to endurance training and to improve performance. The aims of RT were to support muscle hypertrophy, strength and sports performance. It is the only day within which Subject 3 did not report the aim of fat loss and reported two training sessions of RPE $\geq$ “Hard”. Figure 9 demonstrates consideration of the timeframes of PEN analysis according to the decision tree provided in Chapter 2, Figure 3. According to the individual’s stated aims, duration and intensity of exercise sessions and an overview of macronutrient intake recommendations provided in Chapter 4 and Chapter 6, carbohydrate intake was analysed six hours before the first ET, during both ET sessions, between two ET sessions and after the second ET until the recorded bedtime in support of ET adaptation and performance. Protein intake requirements were assessed an hour pre-, during and up to 24 hours post-RT (including protein intake within an hour before bedtime). As an example, the PEN prescription offered high carbohydrate availability throughout a day with a recommendation of “sleep low” after the second ET session in support of ET adaptation and performance. In support of RT (i.e. muscle hypertrophy and strength gain), the equally distributed, optimised protein intake per EO within waking hours up to 24 hours post-RT, including pre-sleep protein intake, was considered as adequate nutrient intake.

In summary, two different nutrient intakes were analysed for two different types and aims of training sessions. The dietary analyses of carbohydrate intake specific to two ET sessions and protein intake tailored to RT session were performed independently and no macronutrient intakes had to be compromised for one of the sessions in this scenario. In practical settings, the amendments to subject’s intake could promote high
carbohydrate intake pre-ET 1, and between two ET sessions to support ET quality according to subject’s aims (i.e. work on technique and different intensities) and to attenuate muscle protein breakdown pre-RT. Restricted carbohydrate intake post-second ET could be recommended to support ET adaptation. Figure 10 illustrates the duration of PEN analysis of carbohydrate intake patterns peri-ET and protein intake patterns and adequacy peri-RT. Additionally, Figure 10 offers an example of carbohydrate and protein intake patterns to support an individual’s intent using the PEN approach. According to Figure 10, in practice, carbohydrate and protein intake could be optimised within the same EO. The distribution and frequency of EO would be more prominent for protein intake in support of muscle hypertrophy than for carbohydrate intake in support of glycogen resynthesis between two ET sessions. Hence, the remaining daily carbohydrate intake could be distributed between two ET sessions (i.e. within > 10 hours), according to an individual’s preferences.
Figure 9 Example of a decision-making process of PEN analysis for multiple exercise sessions for Subject 3 (Day 3)

Note. PEN—Peri-exercise nutrition; EO—Eating occasion/s; ET—Endurance training; RT—Resistance training.
Figure 10 Schematic representation of PEN analysis and nutrient intake prescription tailored to multiple exercise sessions and intent for Subject 3 (Day 3)

Note: ET—Endurance training; ET 1—First endurance training reported on Day 3; ET 2—Second endurance training reported on Day 3; ET 3—First endurance training reported on Day 4; RT—Resistance training.
7.7. Discussion

Endurance-trained individuals, classified according to the five-point scale by De Pauw et al. (2013), were recruited to this study from local cycling and triathlon clubs. According to subjects’ exercise programmes, Subject 1, Subject 2 and Subject 3 reported 60% \((N = 3)\), 33% \((N = 2)\) and 11% \((N = 1)\) of ET sessions respectively, at intensities near or above their lactate threshold in their weekly microcycle. In comparison to endurance athletes who implemented 20% of their exercise programmes at intensities near or above their lactate threshold and train 10–12 times weekly (Seiler and Tonnessen 2009), Subject 1 and Subject 2 performed more sessions at higher intensities and had a lower frequency of training sessions within a weekly microcycle. Subject 3 trained at lower intensities, but more frequently than the two other subjects.

7.7.1. Traditional Dietary Analysis

Data collection of individuals’ EEE allowed analysis of the adequacy of EA and macronutrient intakes within a 7-day weekly microcycle (see Chapter 3, Section 3.8.2.1. for details). Energy availability of 45 kcal·kg FFM\(^{-1}·d^{-1}\) was required to support optimal health and sports performance. The periodisation of 30–45 kcal·kg FFM\(^{-1}·d^{-1}\) was set as adequate on days when a subject aimed for fat loss (Loucks et al. 2011). Average EA assessed for seven days was optimal for one of the three participants, who on average reported ≥ 45 kcal·kg FFM\(^{-1}·d^{-1}\). Subject 1 and Subject 2 had EA of > 50 kcal·kg FFM\(^{-1}·d^{-1}\) during rest days, which compensated for lower energy availability on TD and CD. On CD, the subjects’ EA was between 35 and 45 kcal·kg FFM\(^{-1}·d^{-1}\). The EA values could be corrected by increasing carbohydrate intake on CD, for which the lower threshold of carbohydrate intake was not met (< 5 g·kg\(^{-1}·d^{-1}\)) by Subject 1.

For this study, Subject 3 recorded his dietary intake during his off-season and one of his goals during TD was to reduce fat mass. Thus, the EA target for this subject was set up for 30–45 kcal·kg FFM\(^{-1}·d^{-1}\) on days \((N = 4)\) when the subject reported the fat loss goal and at 45 kcal·kg FFM\(^{-1}·d^{-1}\), when this intent was not given \((N = 3)\). Despite lower EA requirements, Subject 3 failed to meet EA requirements for all seven recorded days. Additionally, EA was < 30 kcal·kg\(^{-1}\) FFM·d\(^{-1}\) on six of seven recorded days. The inadequate energy intake may result in increased prevalence of illness (Drew et al. 2017), bone injuries (Heikura et al. 2018b), decreased mood (Hagmar et al. 2013) and altered levels of metabolic hormones (e.g. testosterone, leptin) (Geesmann et al. 2018).
One of the concurrent goals reported by Subject 3 was to improve performance. However, the consequences of low EA may have a negative consequence on sports performance (Mountjoy et al. 2014).

The adequacy of subjects’ average daily protein intake was evaluated by comparison to the recommendations between 1.2 and 2.0 g·kg⁻¹·d⁻¹ (Thomas et al. 2016). Within this range, average protein intake was exceeded by Subject 1 and met by Subject 2 on TD, RD and CD. Subject 1 exceeded protein intake on six of seven recorded days. Within the provided ranges of protein intake, Subject 2 failed to meet the requirements by exceeding recommended protein intake on 40% of all TD ($N = 5$) or consuming less than required on CD by 8–9% (i.e. 0.1 g·kg⁻¹·d⁻¹).

In line with the scientific literature, 1.6–2.2 g·kg⁻¹·d⁻¹ of protein is recommended in support of RT muscle hypertrophy (Maughan et al. 2018). Nevertheless, higher protein intake, i.e. 1.6–2.4 g·kg⁻¹·d⁻¹ would be expected to preserve lean tissue mass during energy deficit conditions (Hector and Phillips 2018). Although Subject 3 aimed for fat mass loss, he remained in an energy deficit condition of EA < 25 kcal·kg⁻¹ FFM·d⁻¹; and he failed to meet the lower threshold protein intake requirement of 1.6 g·kg⁻¹·d⁻¹. Additionally, on Day 3, Subject 3 reported an RT session in support of muscle hypertrophy and strength gain. On that day, Subject 3 met the lower threshold of protein intake, i.e. 1.6 g·kg⁻¹·d⁻¹.

In comparison to protein intakes of high-performance athletes reported by other authors (Burke et al. 2003; Erdman et al. 2013), only Subject 2 had a comparable protein intake on TD and RD. Protein intake [1.5 (0.4) g·kg⁻¹·d⁻¹] of Dutch endurance male athletes (Gillen et al. 2017) was 13% lower than 7-day average protein intake by Subject 1, 80% lower than protein intake by Subject 2 and 27% higher than protein intake by Subject 3. Subjects who did not aim for fat mass loss met or exceeded average protein intake and had comparable or higher intake than endurance athletes reported in other studies.

The general recommendation for daily carbohydrate intake during a moderate exercise programme of approximately one hour duration is 5–7 g·kg⁻¹·d⁻¹ (Burke et al. 2011). Carbohydrate intake requirements in this study were calculated for all recorded days for all three participants according to the reported EEE, recommended EA and other macronutrient intake values (see Chapter 3, Section 3.8.2.1 for details). The average
range of carbohydrate intake is provided in Table 31. The calculated carbohydrate requirement for Subject 1 and Subject 2, who did not report the aim of fat mass loss, was 6–9 g·kg⁻¹·d⁻¹ on TD. Subject 1 and Subject 2 had adequate carbohydrate intake on 3–4 days over the reported seven days. However, Subject 1 did not meet daily recommended 7–10 g·kg⁻¹·d⁻¹ of carbohydrate intake on CD. To increase carbohydrate availability, Subject 1 could aim for lower but within range of protein and fat intake (i.e. 1.2 g·kg⁻¹·d⁻¹ of protein and 20% of TEI for fat) on CD and on TD, which proceeded CD. Subject 2 also competed on one occasion during the data recording. However, Subject 2 considered the competition event as a “preparation for the next season” and an opportunity to improve endurance training adaptation. Moreover, the duration of the competition event was ~30 minutes. As per the recommended carbohydrate intake (Burke et al. 2011), this event could be supported according to daily carbohydrate requirements of > 7 g·kg⁻¹·d⁻¹, which for this subject was calculated as 5–8 g·kg⁻¹·d⁻¹ on CD, and this requirement was met.

On Day 3, Subject 3 reported three exercise sessions of which one was RT. That day, the participant aimed to support training adaptation and sports performance, not body fat loss, which indicates a deliberate modification of energy availability (i.e. 43 kcal·kg FFM⁻¹·d⁻¹) and protein intake (i.e. 1.6 g·kg⁻¹·d⁻¹) according to a set goal. Nevertheless, Subject 3 did not meet lower recommended carbohydrate intake (i.e. 6 g·kg⁻¹·d⁻¹) on that day and on any other day within a weekly microcycle. The two subjects in-season had adequate carbohydrate intake on 3–4 days and the one subject in off-season failed to meet the carbohydrate intake requirements.

Daily recommended fat intake was set as 20–35% of TEI and lower fat intake of ≤ 20% of TEI might not benefit performance (Thomas et al. 2016). In this current study, each subject met fat intake requirements for 1–3 days of seven days recorded and exceeded the recommended intake above 35% of TEI on the remaining days. High fat intake by a subject could impair intake of other macronutrients. Overall, the amended fat intake could improve carbohydrate consumption on TD and CD when exercise sessions of higher intensities were recorded. Burke et al. (2017a) showed that high fat intake increased fat oxidation when carbohydrate intake was below 50 g·d⁻¹. In this current study, Subject 1 and Subject 2 had moderate carbohydrate intake. Lower, but > 200 g·d⁻¹ of carbohydrate was reported on TD by Subject 3 who aimed to decrease body fat mass. Burke et al. (2017a) reported that 8.7 g·kg⁻¹·d⁻¹ of carbohydrate intake
improved performance of > 5% in elite endurance athletes (i.e. race walkers), while a high-fat diet did not. Moreover, a high fat, low carbohydrate diet appeared to reduce endurance economy at higher intensities (> 70% VO$_2$max) when consumed for 3–4 weeks (Burke et al. 2017a; Shaw et al. 2019). However, Shaw et al. (2019) indicated that endurance exercise economy was not impaired at exercise intensity < 60% VO$_2$max during high-fat, low-carbohydrate regimens in endurance-trained individuals. Burke et al. (2017a) and Shaw et al. (2019) showed that a high carbohydrate diet supports endurance performance, while a high-fat diet could be considered short-term when the aim is to lose body fat mass. Thus, all subjects could improve carbohydrate intake by decreasing fat intake since they all aimed to either improve adaptation to endurance training or to improve performance.

7.7.2. PEN Analysis

The PEN analysis investigated the patterns of carbohydrate availability peri-ET and peri-endurance competition. Since there is more than one opportunity to optimize the carbohydrate intake strategy, adequacy of carbohydrate intake was not assessed within a periodised approach peri-ET (Bartlett et al. 2013; Impey et al. 2018).

Specific to the first aim for PEN analysis, provided in Section 7.4., three patterns of periodised carbohydrate availability peri-ET were examined according to definitions provided by Burke et al. (2018) and summarized in Chapter 6. Firstly, carbohydrate intake analysis was set for six hours before and during ET to investigate whether the first ET of a day was performed with low exogenous carbohydrate intake or in a fasted state. Secondly, if two ET sessions were reported in a day, the carbohydrate intake was analysed between these two sessions and during the second ET to evaluate whether the second ET of the day was performed with a reduced or depleted glycogen store. Lastly, carbohydrate intake was examined after the last ET of a day to investigate whether subjects restricted carbohydrate intake before bedtime. These strategies were shown to promote adaptation to endurance training and fat oxidation when 30–50% of ET sessions were performed with restricted carbohydrate availability (Impey et al. 2018).

Restricting carbohydrate intake six hours pre-ET (Burke et al. 2018) or training in the fasted state (Akerstrom et al. 2006) were shown to increase fat oxidation, in comparison to trials with carbohydrate intake. Additionally, pre-ET undertaken in the fasted state was shown to improve adaptation to ET (Stannard et al. 2010; Van Proeyen
et al. 2011). During two days (Day 2 and Day 3), Subject 1 trained twice a day and aimed for VO\textsubscript{2}max and performance improvement. On two ET session days (Day 2 and Day 3), Subject 1 reported restricted carbohydrate intake of 0.35 g·kg\textsuperscript{−1} within six hours pre-ET. Subject 2 reported one day (Day 1) with two ET sessions during which the aim was to support endurance training adaptation. Before the first session of the day, high carbohydrate availability was assured (1.8 g·kg\textsuperscript{−1}). Both subjects refueled between two sessions and after the second ET but no carbohydrate was consumed during ET sessions. The aims of Subject 3 were to enhance ET adaptation and to improve performance during the first session of the day and additionally to lose fat mass during the second session of the day (Day 1, 2 and 4). Subject 3 did not consume or minimize (to 0.1 g·kg\textsuperscript{−1}) carbohydrate intake before three of four ET sessions on days when two ET were reported. Of three subjects, only Subject 3 did not consume carbohydrate six hours before ET sessions, on the two of four TD when he trained twice daily.

Hansen et al. (2005) demonstrated that training twice a day, commencing the second ET with decreased glycogen store due to overnight fast and carbohydrate withholding between two ET sessions separated by two hours, resulted in greater adaptation to ET than when a single session per day that began with high glycogen stores. In the current study, Subject 3 limited his carbohydrate intake to 0.8–1 g·kg\textsuperscript{−1} between two ET sessions, separated by 6–11 hours on two different double ET days, rather than commencing an ET session in a fasted state. The data do not demonstrate that the other two subjects manipulated their carbohydrate intake to commence an ET session with low muscle glycogen stores.

When only one ET session of 25–125 minutes duration and RPE of 2–5 was performed per day to improve ET adaptation, carbohydrate intake was not restricted within the six hours pre-ET, nor was ET performed within the fasted state. Carbohydrate intake before most single sessions was consumed between 1 and 2.7 g·kg\textsuperscript{−1}·6h\textsuperscript{−1}, except for one session for which carbohydrate intake was < 1 g·kg\textsuperscript{−1}·6h\textsuperscript{−1}. The exception was two ET sessions during which subjects aimed to improve performance. Subject 2 and Subject 3 reported evening run sessions of different intensities, i.e. Subject 2 in Zone 2 for 60 minutes on Day 2 and Subject 3 in Zone 1 for 70 minutes on Day 7. Both subjects recorded carbohydrate intake six hours pre-ET. Specifically, Subject 2 did not provide 1–4 g·kg\textsuperscript{−1} within 1–4 hours pre-ET to support performance (Burke et al.
Subject 3 restricted carbohydrate intake within four hours pre-ET to 0.2 g·kg$^{-1}$, which could support fat oxidation reported for this session together with endurance and performance improvement. In line with the discussed data, training with low liver glycogen stores on days when one ET session, was recorded was not a common approach among these individuals. Moreover, these results indicate that patterns of carbohydrate intake do not clearly support periodised nutrient intakes according to individuals’ intent.

A small amount of carbohydrate intake provided with beverages or carbohydrate mouth rinse could be considered during sessions of higher intensities. Endurance exercise of between 1–2 hours may require carbohydrate intake of 30 g·h$^{-1}$ (Jeukendrup 2014). In this current study, the average duration of endurance exercise was approximately one hour for all three subjects. Among recorded training sessions, only Subject 2 recorded 18 g of carbohydrate intake during a 45 minute swim session of RPE 4 (Day 4) and 60 g (i.e. 30 g·h$^{-1}$) of carbohydrate during an approximately two hour-long cycle session of RPE 5 (Day 6). During both sessions, Subject 2 aimed to improve training adaptation. Subject 1 consumed 67 g (i.e. 42 g·h$^{-1}$) during a 96 minute race of RPE 5. The data indicate that carbohydrate intake during exercise was consumed for sessions of > 60 minutes duration, within norms to support performance. However, carbohydrate intake was not necessary for 45-minute sessions of lower intensity.

The second objective of the PEN analysis was to examine patterns and adequacy of high carbohydrate availability four hours pre-, during and four hours post-competition sessions. High carbohydrate availability pre- and during endurance exercise is recommended for key ET sessions and peri-competition events lasting > 60 minutes to support sports performance [i.e. 1–4 g·kg$^{-1}$ 1–4 hours pre-exercise (Burke et al. 2011), 30–60 g·h$^{-1}$ during events of 1–3 hours duration (Jeukendrup 2014)]. Carbohydrate intake refueling post-endurance exercise is recommended if the goal is to enhance glycogen restoration within the restricted recovery phase between two competition events (i.e. 1.0–1.2 g·kg$^{-1}$·h$^{-1}$ for four hours post-exercise if recovery is < 8 hours) (Burke et al. 2011). Additionally, protein intake was examined post-endurance exercise when carbohydrate intake was below the optimal intake, i.e. < 1.2 g·kg$^{-1}$·h$^{-1}$ (Ivy et al. 2002; Betts and Williams 2010; Burke et al. 2011; Alghannam et al. 2018). Of two endurance competition events recorded by two subjects, Subject 1 consumed
1.3 g·kg⁻¹·4h⁻¹ before a cycling race, and fuelled according to guidelines (Burke et al. 2011) during a race (Day 7). However, Subject 1 did not report energy and nutrient intakes within four hours post-race. Subject 2 recorded a competition event on Day 7 but the ~30-minute race was considered by Subject 2 as a training session of higher intensity (Zone 2) to improve endurance. Carbohydrate intake of 3.2 g·kg⁻¹·4h⁻¹ pre-race met the requirements of 1–4 g·kg⁻¹ pre-fuelling. However, the duration of the competition event (<60 minutes) neglected the necessity of carbohydrate intake within four hours before the race (Burke et al. 2011). No carbohydrate was consumed during the race, which lies within the recommendations for this competition (Burke et al. 2011).

Within the first four hours post-endurance exercise, Subject 2 consumed 2.3 g·kg⁻¹·4h⁻¹ of carbohydrate and 0.7 g·kg⁻¹·4h⁻¹ of protein in one EO. It can be considered that carbohydrate intake requirements were met for both competition events before and during a session, even if the intake was not required for a competition event reported by Subject 2. Within four hours post-endurance competition events, subjects did not meet the carbohydrate intake requirements. However, both subjects had longer recovery periods than eight hours, hence they did not have to follow the rapid refuelling strategy within four hours post-race and could follow their habitual intake (Burke et al. 2017b). Lastly, high carbohydrate availability of 10–12 g·kg⁻¹·24h⁻¹ is recommended for 36–48 hours before a competition event that lasts >90 minutes and 7–12 g·kg⁻¹·24h⁻¹ if the event is <90 minutes (Burke et al. 2011). Hence, when Subject 1 competed for 96 minutes, his carbohydrate intake 48 hours pre-race was compared to 10–12 g·kg⁻¹·24h⁻¹. Subject 1 did not meet the carbohydrate loading requirements.

Patterns of carbohydrate and protein intake were assessed according to set objectives for all reported exercise sessions, including sessions other than endurance exercise. As stated in Section 7.4, the third objective of the PEN analysis was to evaluate the pattern and adequacy of protein intake according to the recommended protein intake peri-RT (see Chapter 4 for details). A pattern of carbohydrate co-ingestion with suboptimal protein intake peri-RT was examined. Subject 3 reported two RT sessions and provided the aim and RPE for one of them. Hence, the PEN analysis was conducted for one RT session. Since Subject 3 aimed to improve adaptation to RT, the protein and carbohydrate intake was assessed similarly to the prescription provided in Chapter
4 (see Table 12). No EO was consumed one hour pre-, during RT and one-hour pre-bedtime. Within 24 hours post-RT, Subject 3 recorded five EO with a mean distribution of 03:23 (02:18) hh:mm and consumed the recommended protein intake of 1.6 g·kg⁻¹·24h⁻¹. Average distribution of total protein intake post-RT supported muscle hypertrophy and strength gain (Moore et al. 2009a; Areta et al. 2013; Maughan et al. 2018). However, the quantity of protein intake per EO could have been optimised by Subject 3. Only one EO met the recommendations of 0.3–0.5 g·kg⁻¹·EO⁻¹ (Maughan et al. 2018). Mean carbohydrate of 0.7 (0.3) g·kg⁻¹·EO⁻¹ was co-ingested with suboptimal protein intake (i.e. < 0.3 g·kg⁻¹·EO⁻¹). Despite total protein intake, frequency and mean distribution of EO post-RT were optimal, thus, protein quantity per EO should be optimised in support of RT adaptation (Moore et al. 2009a).

In this current study, carbohydrate intake patterns were analysed when either single or multiple exercise sessions occurred during a single day. The last objective of this chapter was to demonstrate the PEN analysis of multiple sessions reported in one day. The day with three training sessions recorded was used to outline a roadmap of setting timeframes of dietary analysis (see Figure 9). The duration of nutrient intake assessment was informed by the scientific evidence (Chapter 4 and Chapter 6), and a decision tree provided in Figure 3 in Chapter 2. Moreover, an example of carbohydrate and protein intake patterns in support of an individual’s goals is illustrated in Figure 10. In this example, recommendations of carbohydrate intake peri-ET and protein intake peri-RT according to an individual’s intent, were not conflicting. This could be achieved as there are multiple opportunities to manipulate carbohydrate periodisation, of which one was offered in support of Subject 3’s goals in the reported sequence of training sessions. In addition, it should be noted that the reported multiple goals for ET sessions allowed for the extended examination of dietary practices within a microcycle. However, more focused goals would allow the implementation of tailored carbohydrate intake strategies in practice.

7.8. Conclusions
This case study analysis of the dietary intake of three endurance-trained males found the average daily EA and/or macronutrient intake recommendations were met on 0–4 days. Thus, daily EA and macronutrient intakes were suboptimal. However, PEN analysis demonstrated that the adequacy of nutrient intake for individual training and competition days could be improved further. As an example, analysis of the patterns
of peri-ET carbohydrate intake revealed that subjects randomly withheld carbohydrate intake pre-, between- or post-ET session when training twice a day or pre-ET when training once a day in support of ET adaptation. Rather, the evidence suggests that suboptimal peri-ET carbohydrate intake practices coincided with suboptimal daily carbohydrate intake. The most prominent example of an athlete training with low or restricted peri-ET carbohydrate intake between two ET sessions was shown by Subject 3. Yet, it is worth noting that EA and carbohydrate intake were below the recommended intake on most of the days within the weekly microcycle for this subject, i.e. was facilitated by lower than recommended daily carbohydrate intake. This level of analysis was also able to distinguish between a subject who was in-season, aiming to improve endurance performance and who maintained a greater average daily EA, protein and carbohydrate intake and lower fat intake, than a subject in the off-season, aiming for concurrent loss of fat mass.

This case study also demonstrated that a PEN approach to endurance competition could be employed as a valuable addition to the prescribed daily macronutrient intake to optimise the patterns of macronutrient intake on CD and preceding the event. In this case study, adequacy of carbohydrate intake was noted for the four-hour pre- and during endurance competition event of > 90 minutes duration. In a practical setting, the PEN approach could be a valuable addition to dietary assessment for trained individuals, even if daily macronutrient intake practices seem optimal. The evidence-based literature provides guidance to sport and exercise nutrition practitioners, enabling optimised peri-training and peri-competition nutrient strategies in support of training adaptation, sports performance and/or body composition goals.

7.9. Further work
Further work relates to the application of the PEN assessment method in practical settings on a one-to-one basis among different sports disciplines. The PEN analysis could advance daily dietary practices by evaluating and planning carbohydrate periodisation strategies in support of endurance exercise adaptive and performance outcomes among trained individuals. Further work to advance the PEN method is discussed in detail in Chapter 10.
Chapter 8
Peri-Exercise Nutrition in Research: Dietary Standardisation in a Study Investigating Post-Exercise Myofibrillar Protein Synthesis in Resistance-Trained Males

A version of this chapter is in preparation for publication. Kozior, M. Jakeman, P. M., Davies, R. W. Norton, C. 2020. 'Peri-exercise nutrition in research: dietary standardisation in a study investigating post-exercise myofibrillar protein synthesis in resistance-trained males'.
8.1. List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM</td>
<td>One repetition maximum</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>Mdn</td>
<td>Median</td>
</tr>
<tr>
<td>MPS</td>
<td>Muscle protein synthesis</td>
</tr>
<tr>
<td>N/A</td>
<td>Not applicable</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RT</td>
<td>Resistance training</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
</tr>
</tbody>
</table>

8.2. Abstract

Dietary intake patterns within and between study participants may impact researchers’ ability to accurately determine research outcomes. Dietary standardisation aims to minimise differences in nutrient intakes between participants and thus remove confounding variable. The peri-exercise nutrition (PEN) approach offers an advancement to diet standardisation informed by scientific evidence and habitual dietary practices in proximity to exercise. This research aimed to devise a standardised approach to meal plans for use in a nutrient-exercise intervention study. The standardised diet composition was informed by food and beverages habitually consumed by resistance-trained individuals; the diet complied with dietary recommendations and met participants’ food preferences. The framework of the proposed dietary standardisation is a double-blind randomised parallel group design research study investigating the effect of dietary protein supplementation pre-resistance training (RT) on myofibrillar muscle protein synthesis (MPS), post-RT. Twenty-three resistance-trained males (aged 18 to 35 years) received a 72-hour standardisation protocol before commencement of the study. Participants received a six-day meal plan that provided 35 kcal·kg⁻¹·d⁻¹ and consisted of 2 g·kg⁻¹·d⁻¹ of protein, 4.5 g·kg⁻¹·d⁻¹ of carbohydrate and 1.0 g·kg⁻¹·d⁻¹ of fat daily. Daily protein intake was distributed evenly, every three hours, with six eating occasions (EO), including protein supplement. Participants’ compliance was ~97% for time and ~100% for frequency and quantity of nutrient intakes for a standardised diet. After study completion, of participants who correctly completed an online survey (N = 22), 45% (N = 10)
expressed that the standardised diet was easy to follow. Among the given reasons describing the dietary standardisation as difficult to follow, the most frequent reason was the influence of activities of daily living (29% of responses, 10 of 35 responses). The proposed dietary standardisation was an effective approach to minimising the variability of dietary practices among subjects within a nutrient-exercise type of intervention study.

8.3. Introduction

Habitual dietary patterns vary from day-to-day within and between subjects (Erdman et al. 2013; Baranauskas et al. 2015; Parnell et al. 2016; Gillen et al. 2017). In dietary research studies, these observed variations in eating patterns have the potential to impact research outcomes (e.g. performance measurements) within and between groups (Hawley and Burke 1997; Areta et al. 2013; Thomas et al. 2016). Dietary standardisation is a recommended approach to minimising the variability of observed inter- and intra-subjects’ dietary practices. Jeacocke and Burke (2010) defined dietary standardisation as “all methods of minimising pre-existing differences in the dietary intake or nutritional status of participants”. In this research study, the provided dietary standardisation refers to the term proposed by Close et al. (2019), which identifies practices to prescribe a diet for study participants to follow. Dietary replication is another approach in controlling subjects’ nutrient intake prior to or during a research study. Dietary replication is described as a repetition of participant’s diet for each study trial (Close et al. 2019). However, a standardised diet has been shown to be more effective in diet reproducibility than dietary replication (El-Chab et al. 2016). Despite the superiority of standardised diet to dietary replication, a standardised diet has been reported in only 13% of research studies published in the International Journal of Sports Nutrition and Exercise Metabolism between 2004 and 2009 (Jeacocke and Burke 2010). Moreover, Jeacocke and Burke (2010) reported that more than half of screened studies did not report on participants’ compliance to the standardisation protocol or the energy and nutrient intake patterns of participants preceding the trials. Braun and Brooks (2008) suggested that control of dietary intake is an overlooked approach in research. Ideally, the dietary standardisation protocol would represent athletes’ habitual practices, investigated in advance of study (Moncada-Jimenez et al. 2009; Burke et al. 2017a; Mirtschin et al. 2018; Close et al. 2019).
Prior to and during research studies, dietary standardisation decreases extraneous factors, and increases study validity, reliability and sensitivity of performance measurements (Jeacocke and Burke 2010). In sports and exercise nutrition research, dietary standardisation should be devised carefully and should be tailored to the measured outcome (Close et al. 2019). The PEN prescription outlined in the preceding chapters may provide an opportunity to advance dietary standardisation tailored to habitual dietary practices and recommended nutrient intakes for trained populations, within investigations of nutrient-exercise interactions. In this context, the PEN prescription promotes a decrease in the inter- and intra-subject variability in nutrient intakes, on a daily basis. The framework for the proposed dietary standardisation in this chapter is based on a research study investigating the effect of dietary protein supplements on MPS, post-RT. The research study outcomes are described elsewhere (Davies et al. 2020). The dietary habit assessment of a convenience sample of resistance-trained males, as previously reported in this thesis, provided the basis for the standardised diet used to control participants’ nutrient intakes. This research necessitated the consumption of a dairy-derived protein pre-RT at a dose of 0.33 g·kg\(^{-1}\)·d\(^{-1}\). For the average male participant (~80 kg body mass) this supplement would have represented only ~16% of total protein consumption, based on previously reported daily habitual protein intake of [mean (M) (SD)] 2.1 (0.5) g·kg\(^{-1}\)·d\(^{-1}\) (N = 35) on training days (Chapter 5, Section 5.6.2.). Daily residual and uncontrolled patterns of protein intake (~84%) could alter the measured MPS outcome in a research study (Moore et al. 2009a; West et al. 2011; Moore et al. 2012; Areta et al. 2013). In order to ensure that observed changes to outcome measures were attributable to the intervention and not to variation in habitual dietary intake practices among resistance-trained individuals, dietary standardisation was implemented to control nutrient intakes in the resistance-trained population. Furthermore, dietary standardisation necessitated the development of dietary meal plan and monitoring protocols to eliminate the variability in results.

8.4. Aim

The main aim of this research was to devise a standardised approach to meal plans for use in a nutrient-exercise type of intervention study, which represented the habitually consumed foods and beverages of the resistance-trained individuals, complied with
dietary recommendations, and met participants’ foods preferences. The following objectives were set to fulfil this aim:

1. To develop and apply a personalised dietary plan, based on resistance-trained males’ food preferences and scientific evidence.
2. To collaborate with an external food provider to deliver EO, for which nutrient intakes were tailored to subjects’ body mass.
3. To monitor the standardised protocol in order to increase subjects’ compliance.

8.5. Methods

8.5.1. Ethics
This study conformed to the standards set by the Declaration of Helsinki and was approved by the University of Limerick Education and Health Sciences Research Ethics Committee (2016_12_09 EHS). Participants were familiarised with the study protocol, including risks and benefits associated with participation in the research study, and they provided their written consent forms. The intervention study was pre-registered at https://www.clinicaltrials.gov as NCT03297151.

8.5.2. Participants
Volunteers who met the inclusion criteria [males aged 18 to 35 years; resistance-trained, defined as 0.5 year continuous RT ≥ 3 h·wk⁻¹ before starting the data collection; able to perform a 1.25 kg·kg⁻¹ of body mass barbell back squat one repetition maximum (1RM); no illness, medication, current injury or history of chronic disease; and lactose tolerant] were recruited to the study. Figure 11 outlines the assessment of subjects’ eligibility and the number of participants who completed the 72-hour pre-trial and six-day dietary standardisation protocols.

8.5.3. Study Conduct
The study design and related details were described by Davies et al. (2019) and Davies et al. (2020).

8.5.3.1. Dietary and Physical Data Collection and Coding
Dietary and physical activity data were collected and coded according to the standards described in Chapter 3. The customised version of Nutritics Ltd. (Ireland) nutrition software (Kozior et al. 2019) was used for data coding and energy and nutrient intakes analysis.
8.5.3.2. Development of Dietary Standardisation

A standardised meal plan was developed based on the EO information provided by resistance-trained individuals, their reported food preferences and habitual nutrient intake practices. Commonly consumed food items and typical meals for this group of resistance-trained individuals were identified and included in the implemented meal plan. The habitual quantity and quality of nutrient intakes, and distribution per eating occasion, were amended according to recommendations for protein intake, timing, frequency and distribution peri-resistance training (as outlined in Chapter 4). The meal plan was designed to provide 35 kcal·kg⁻¹·d⁻¹ of energy, 2 g·kg⁻¹·d⁻¹ of protein, 4.5 g·kg⁻¹·d⁻¹ of carbohydrate and 1.0 g·kg⁻¹·d⁻¹ of fat every day. Main EO [i.e. breakfasts (except breakfast on Day 1), lunches and dinners] and snacks could be swopped between days, and the same between snacks according to participants’ preferences. This flexibility was given because all main meals and snacks provided the same quantity of energy and macronutrients; an equal amount of protein was spread through the six eating occasions throughout a day.

The meal plan accommodated food allergies and intolerances, and where required, two additional breakfast options were proposed for one participant. The additional EO provided the same energy and macronutrients content as other main EO (breakfasts, lunches and dinners). Due to the incorporation of the biopsy five hours post-RT, the
The proposed breakfast on Day 1 was modified to ensure that MPS response was narrowed to the effect of protein supplementation before the resistance training. Therefore, the breakfast on Day 1 was different from breakfasts between Day 2 and Day 6. Table 34 describes energy and macronutrient intakes for main meals and snacks for all six days. The six-day menu met or exceeded the Dietary Reference Intakes for micronutrients (Institute of Medicine 2000b; Public Health England 2016), including sodium, potassium, calcium and magnesium, which have a favourable effect on the maintenance of normal muscle contraction (Turck et al. 2018). The exception was the daily Recommended Dietary Allowance for Vitamin D, for which the dietary programme met requirements in ~50%. Consumption of each meal or snack was prescribed every three hours, as per EO distribution and optimal protein feeding patterns previously discussed in Chapter 4.

Table 34 Daily and per eating occasion energy and macronutrient distribution within the prescribed six-day meal plan

<table>
<thead>
<tr>
<th></th>
<th>Energy (kcal·kg⁻¹)</th>
<th>Protein (g·kg⁻¹)</th>
<th>Carbohydrate (g·kg⁻¹)</th>
<th>Fat (g·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein Supplement</td>
<td>~1.3</td>
<td>0.33</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Breakfast¹</td>
<td>9</td>
<td>0.33</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Lunch</td>
<td>9</td>
<td>0.33</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Afternoon snack</td>
<td>4</td>
<td>0.33</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Dinner</td>
<td>9</td>
<td>0.33</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Pre-sleep snack</td>
<td>4</td>
<td>0.33</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Total intake Day 1¹</td>
<td>32</td>
<td>1.7</td>
<td>4.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Total daily intake Days 2–6</td>
<td>35</td>
<td>2.0</td>
<td>4.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Average daily intake Days 1–6</td>
<td>34</td>
<td>1.9</td>
<td>4.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Note. ¹Breakfast on Day 1 was different from the rest of the days due to the basal biopsy after breakfast. Breakfast provided: energy 5 kcal·kg⁻¹, protein 0.05 g·kg⁻¹, carbohydrate 0.8 g·kg⁻¹, and fat 0.2 g·kg⁻¹. N/A-Not applicable.

In all EO (N = 35), the primary source of protein was an animal source (i.e. milk, yoghurt, cheese, eggs, fish, meat), except breakfast on Day 1 (Table 35). Daily average sources of protein intake were [median (Mdn) (25th–75th percentiles)] 28 (25–29)%
plant and 72 (71–75)% animal. Table 35 shows sources of protein intake per EO, main EO (breakfasts, lunches, dinners) and snacks (afternoon snacks and pre-sleep snacks) including a dietary supplement expressed in percentage of total protein intake.

Table 35 Protein source per EO in the prescribed six-day meal plan

<table>
<thead>
<tr>
<th></th>
<th>Plant source (%)</th>
<th>Animal source (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All EO (N = 36)</td>
<td>31 (11–43)</td>
<td>69 (57–89)</td>
</tr>
<tr>
<td>Main EO (N = 18)</td>
<td>42 (33–53)</td>
<td>58 (47–67)</td>
</tr>
<tr>
<td>Snacks (N = 12)</td>
<td>15 (11–29)</td>
<td>85 (71–89)</td>
</tr>
<tr>
<td>Dietary supplement (N = 6)</td>
<td>0 (0–0)</td>
<td>100 (0–0)</td>
</tr>
</tbody>
</table>

*Note. Data are medians (25th–75th percentiles); EO–Eating occasion/s.*

Due to limitations in the available nutrition analysis software, it was not possible to assess amino acid content of the prescribed meal plan at the time it was conceived. Subsequent estimation of meal plan leucine content was carried out using the United States Department of Agriculture (USDA) data source (USDA National Nutrient Database for Standard Reference 28 Software v.3.8.6.1). Table 36 shows daily and per EO leucine intake, relative to participants’ body mass. Average leucine intake per main meal was [\( Mdn \) (25th–75th percentiles)] 0.02 (0.02–0.03) g·kg\(^{-1}\) and per snack was 0.02 (0.02–0.02) g·kg\(^{-1}\). Absolute leucine intake was 1.8 (0.3) g per main EO (excluding breakfast on Day 1) and 1.5 (0.3) g per snack. Table 37 presents the EO provided during the six-day study. Additionally, a menu of 30 EO was presented to participants for agreement before the research study began.

Table 36 Leucine content (g·kg\(^{-1}\)) in the prescribed six-day study meal plan

<table>
<thead>
<tr>
<th></th>
<th>Breakfast (g·kg(^{-1}))</th>
<th>Lunch (g·kg(^{-1}))</th>
<th>Afternoon snack (g·kg(^{-1}))</th>
<th>Dinner (g·kg(^{-1}))</th>
<th>Pre-sleep snack (g·kg(^{-1}))</th>
<th>Total (g·kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>0.006</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>Day 2</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>Day 3</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>Day 4</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>Day 5</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>Day 6</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.11</td>
</tr>
</tbody>
</table>

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8.5.3.3. Production and Delivery of Standardised Diet
A catering company external to the primary research team was employed to produce and provide EO based on recipes prepared by the author, for each subject. The order was sent once weekly following allocation to treatment groups in the intervention study. Chefs received recipes relative to the body mass of participants and they separately prepared EO for each individual. Recipes provided the brand name of products, quantities of ingredients (including salt and seasonings) and cooking methods. The same product brands were used during the entire study. Disposable food containers were used for daily EO delivery. Each main meal and snack was labelled with participant’s code, name of EO, and prescribed date and time of its intended consumption. All EO were checked for their completeness prior to dissemination to participants. The overview of foods provided for EO over six days is presented in Table 37 and Figure 12.

8.5.3.4. Dietary Standardisation 72 Hours Before the Research Study
Seventy-two hours prior to the study, participants were asked to refrain from alcohol, caffeine and dietary supplement intakes, and to continue this throughout the study (nine days in total). The additional information regarding dietary standardisation before and during the research study was provided and revised with participants to ensure compliance to the dietary protocol (see Appendix 6).
### Table 37 Six-day meal plan prescribed for resistance-trained individuals

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breakfast</strong></td>
<td>Porridge made with rice milk, coconut oil and banana topped with cranberries and honey&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Boiled eggs with avocado and cherry tomatoes on toast, apple juice, and red grapes</td>
<td>Milk and yoghurt shake with banana, peanut butter and honey, topped with oats</td>
<td>Porridge with cashews topped with honey</td>
<td>Omelette with mushrooms, tomato and spinach, white bread, and orange juice</td>
<td>Poached eggs with grilled bacon rasher, grilled tomatoes, and fruit smoothie</td>
</tr>
<tr>
<td><strong>Lunch</strong></td>
<td>Poached eggs with asparagus and sweet potato chips, orange juice</td>
<td>Mexican chicken wrap, mango, grapes and banana salad</td>
<td>Butter chicken curry with brown rice, kiwi, apple and lime smoothie, and red grapes</td>
<td>Beef burger on a multigrain bun with coleslaw salad, orange juice, and banana</td>
<td>Beef stir fry with vegetables and rice, banana</td>
<td>Roasted pork with beetroot salad, and baked sweet potatoes</td>
</tr>
<tr>
<td><strong>Snack</strong></td>
<td>Ham sandwich with tomato and lettuce, fat-free fruit yoghurt</td>
<td>Greek yoghurt with oats, nuts and raspberries</td>
<td>Ham sandwich with tomato and lettuce, and fat-free fruit yoghurt</td>
<td>Pasta with pesto and grilled turkey</td>
<td>Granola fruit and nut yoghurt topped with honey</td>
<td>Tuna salad with bread on the side</td>
</tr>
<tr>
<td><strong>Dinner</strong></td>
<td>Grilled chicken breast in gravy with boiled sweetcorn, peas, baby carrots and mashed potatoes, strawberry and banana smoothie</td>
<td>Beef bourguignon, apple and pear</td>
<td>Roasted chicken breast with gravy, boiled broccoli, carrots and potatoes, and dried fruit</td>
<td>Beef stroganoff</td>
<td>Baked salmon with asparagus and mashed potatoes</td>
<td>Spaghetti bolognese, and blueberries</td>
</tr>
<tr>
<td><strong>Pre-sleep snack</strong></td>
<td>Greek yoghurt with cashews and fresh berries topped with honey</td>
<td>Blueberry, milk and yoghurt shake</td>
<td>Wholemeal toast with a slice of tomato, and cottage cheese with chives</td>
<td>Yoghurt with an oatmeal bar</td>
<td>Yoghurt and Weetabix biscuits</td>
<td>Yoghurt with granola, green grapes</td>
</tr>
</tbody>
</table>

**Note.**<sup>1</sup>Breakfast on Day 1 was different from the rest of the breakfasts due to the basal biopsy after breakfast. Breakfast on Day 1 provided 5 kcal·kg<sup>-1</sup>, composed of 0.05 g·kg<sup>-1</sup> of protein, 0.8 g·kg<sup>-1</sup> of carbohydrate, and 0.2 g·kg<sup>-1</sup> of fat.
8.5.3.5. Dietary Standardisation During the Research Study

Participation in the intervention study, which was the backdrop for the dietary standardisation, required consumption of a protein-based dietary supplement dissolved in 500 ml of water. The protein-based supplement was the first EO consumed in the morning (every second day the beverage was consumed before an RT session). Three main EO (breakfast, lunch, dinner) and two snacks (afternoon and pre-sleep) were prescribed per unit body mass and provided daily for six days. Participants consumed a supplement and breakfast under supervision at the research unit of the University. The remaining four EO were consumed daily in the participants’ own environments. Participants could reheat EO according to their preferences. On the first day of the research study, participants consumed a low-protein (≤ 5 g·EO⁻¹, i.e. 0.05 g·kg⁻¹), plant-based breakfast and one of three, protein-based supplements at the same time point after the baseline muscle biopsy, and before the first RT session. On Day 1, participants did not consume other energy-containing food and beverages until the
second biopsy was taken, i.e. ~5 hours post-RT session (Davies et al. 2019). Therefore, participants consumed five not six EO on Day 1, in comparison to the remaining five days. It was the only difference between Day 1 and other days within the six-day intervention (Davies et al. 2020). All other EO were distributed across each day, to occur every three hours within waking hours. A list of low-protein (< 1.5 g·EO⁻¹), plant-based snacks (98–104 kcal·EO⁻¹, 24–26 g·EO⁻¹ of carbohydrate) and alternative food and beverages options were provided to participants (Appendix 7) if they craved savoury or sweetened food or beverages between planned EO. Every day, participants received checklists to monitor their compliance to the prescribed diet (Appendix 8). The daily checklists allowed participants to report their food and beverage intakes from the snack list, EO not provided within the research study, food leftovers or any changes made to prescribed frequency and distribution of EO. Food grade weighing scales (DYMO M2®, USA) were provided to all participants for the duration of the intervention for weighing leftovers or additional food items and fluids they consumed. Lastly, food containers were returned with any remaining leftovers before EO for the next day were provided. This offered an additional opportunity to check participants’ compliance to the prescribed diet plan.

8.5.3.6. Assessment of Participant Experience

Following the study completion, subjects were asked to provide feedback about their experience with a standardised diet. Participants were provided with the link to the online survey on the Survey Monkey® platform (www.surveymonkey.com). A multiple choice question was asked to assess participants’ difficulty in following the dietary standardisation, while rationale for the given answer was offered with free text response boxes. Participants were asked about the usefulness of a snack list in adhering to a prescribed protocol. A close-ended, multiple choice question was provided to participants to assess their willingness to modify their habitual intakes peri-resistance training.

8.5.3.7. Statistical Analysis

Comparison of the meal plan prescription for the research study and reported actual energy and macronutrient intakes over six days was conducted using Nutritics Ltd. (Ireland) and MS Excel 2016 software. The statistical analyses were carried out with the Statistical Package for the Social Sciences version 25.0 (SPSS Inc., Chicago IL, USA) and MS Excel 2016. Data were assessed for normality using the Shapiro-Wilk
test and presented as \( M (SD) \) or \( Mdn \ (25^{\text{th}}-75^{\text{th}} \text{ percentiles}) \), as appropriate. The data representing compliance to the prescribed meal plan of the three studied groups were assessed for homogeneity of variance via Levene’s test. The Kruskal-Wallis H test and Bonferroni corrected post-hoc test were used to evaluate the differences between groups \((P < .05)\). Additionally, participants’ study experiences were assessed via the online survey and expressed as a percentage (%).

### 8.6. Results

#### 8.6.1. Participants

Twenty-three volunteers completed the dietary and physical activity intervention. Despite the fact that one participant did not consent to the final biopsy on Day 6, he completed the dietary standardisation and the online exit survey. The anthropometric profile of participants including age, height, body mass, body composition, resistance-training experience and 1RM for the barbell back squat is presented in Table 38.

Table 38 Participants’ baseline characteristics

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>25\text{th}−75\text{th} percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>22.6</td>
<td>20.4−25.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.8</td>
<td>175.5−184.0</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>78.3</td>
<td>71.6−87.7</td>
</tr>
<tr>
<td>Lean tissue mass (kg)</td>
<td>63.4</td>
<td>56.1−66.9</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>18.2</td>
<td>13.9−23.7</td>
</tr>
<tr>
<td>Resistance training experience (y)</td>
<td>2</td>
<td>1.5−4</td>
</tr>
</tbody>
</table>

#### 8.6.2. Compliance to the Standardised Protocol

Average compliance with the six-day meal plan was 100 (99−100)\%, 100 (100−100)\%, 100 (99−100)\% and 100 (99−100)\% for energy, protein, carbohydrate and fat, respectively. There was non-statistically significant difference in energy and macronutrient intakes over six days between the three groups for energy \([H(2) = 1.527, P = .466]\), protein \([H(2) = .818, P = .664]\), carbohydrate \([H(2) = 1.412, P = .494]\) and fat \([H(2) = 1.407, P = .495]\). Compliance to the prescribed meal plan per group over six days is presented in Table 39.
Table 39 Compliance to the six-day meal plan within groups (\(N = 3\))

<table>
<thead>
<tr>
<th>Groups</th>
<th>Energy ((\text{kcal} \cdot \text{kg}^{-1}))</th>
<th>Protein ((\text{g} \cdot \text{kg}^{-1}))</th>
<th>Carbohydrate ((\text{g} \cdot \text{kg}^{-1}))</th>
<th>Fat ((\text{g} \cdot \text{kg}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ((N = 7))</td>
<td>34 (34–34)</td>
<td>1.9 (1.9–1.9)</td>
<td>4.3 (4.3–4.4)</td>
<td>1.0 (1.0–1.0)</td>
</tr>
<tr>
<td>2 ((N = 8))</td>
<td>34 (34–34)</td>
<td>1.9 (1.9–1.9)</td>
<td>4.4 (4.4–4.4)</td>
<td>1.0 (1.0–1.0)</td>
</tr>
<tr>
<td>3 ((N = 8))</td>
<td>33 (34–34)</td>
<td>1.9 (1.9–1.9)</td>
<td>4.4 (4.4–4.4)</td>
<td>1.0 (1.0–1.0)</td>
</tr>
</tbody>
</table>

*Note. Data are medians \((25^{\text{th}}–75^{\text{th}}\text{ percentiles})\).*

Participants \((N = 23)\) complied with the prescribed time of EO consumption in 97 (93–100)%
. Therefore, the distribution of EO intake was 03:04 (03:04–03:05) hh:mm over six days.
There was non-statistically significant difference in EO distribution between groups over six
days \([H(2) = .423, P = .810]\). Compliance to the recommended frequency of EO was met in
100 (100–100)% for all participants, which was 6 (6–6) EO daily over six days.
However, on Day 1, five EO were consumed by all participants, since breakfast and the dietary supplement were consumed at the same

time. There was non-statistically significant difference in number of EO consumed between
groups over six days \([H(2) = 1.132, P = .568]\).

8.6.3. Evaluation of Participants’ Experience in a Research Study

After participation in the study, all participants \((N = 23)\) completed an online survey.

The prescribed diet was easy to follow for 45% \((N = 10)\) of participants and difficult
to follow for 55% \((N = 12)\) of participants. One participant reported that the meal plan
was both easy and difficult to follow, so his answer was excluded from the analysis.
The reasons for the given answers are shown in Figure 13. Participants could give
more than one answer. Participants expressed their interest in modifying or considering
the modification of quantity \((87\%, N = 20)\), timing \((83\%, N = 19)\) of energy and
nutrient intakes, peri-resistance training and distribution of EO throughout a day \((78\%,
\ N = 18)\). In addition, 83% \((N = 19)\) of individuals reported that the snack list was a
useful addition to the proposed meal plan, despite the fact that the additional snacks
had to be purchased by the participants themselves.
Figure 13 Rationales for evaluating the six-day meal programme as either easy or difficult to follow by participants \( (N = 22) \)

### 8.7. Discussion

The main aim of this research was to offer a dietary standardisation in a nutrient-exercise type of intervention study. Pre-experimental, dietary and physical activity data of habitual weekly practices were collected to promote high ecological validity, by considering participants’ food preferences while planning the standardised diet programme. The six-day meal plan was standardised and EO were ready to consume by participants to minimise quantity, quality, frequency, timing and distribution variability of energy and nutrient intakes within- and between-subjects during the intervention. Daily and per EO energy and macronutrient prescription was relative to participants’ body mass and based on the scientific evidence to support the adaptive outcome of RT. The dietary standardisation was particularly important in this six-day intervention, where on average a dietary supplement contributed to only 17% of daily protein intake.

The method to standardise diet for nutrient-exercise interventions developed and described here complies with best practice guidelines (Jeacocke and Burke 2010; Mirtschin et al. 2018). The comprehensiveness of the devised standardisation requires engagement and collaboration between participants, research dietitians, sports scientists and chefs, on a daily basis. Participants were familiar with the purpose of the study and the importance of their engagement. Daily communication with subjects and personalisation of the proposed meal plan before the beginning of the experimental stage resulted in high compliance, which is reported in the results section. The required degree of detail to prepare each meal specific to subjects’ needs (body mass, food
allergies and preferences), required the engagement of a dedicated chef. Furthermore, the implementation and management of dietary standardisation within this study necessitated daily supervision by a research dietitian.

The complexity of a dietary control approach is often underestimated and misunderstood by researchers and might be unspecified during nutritional intervention studies (Jeacocke and Burke 2010). Few researchers have chosen to provide participants with prepacked meals to meet daily energy or macronutrient targets before the intervention (Areta et al. 2013; Lane et al. 2014). Dietary standardisation that is based on participants’ food preferences and relates to participants’ lean tissue mass (Burke et al. 2017a; Mirtschin et al. 2018) or body mass (Louis et al. 2016; Marquet et al. 2016; Rustad et al. 2016) has been proposed in studies investigating the effect of carbohydrate periodisation on performance and other measured outcomes in endurance-trained males (Louis et al. 2016; Marquet et al. 2016; Rustad et al. 2016; Burke et al. 2017a). For example, in the short-term studies by Marquet et al. (2016) and Louis et al. (2016), the effect of carbohydrate periodisation on performance (Marquet et al. 2016), and immunity and sleep (Louis et al. 2016) was investigated in endurance-trained individuals. Participants were given precise dietary guidelines to prepare their meals to meet daily and per EO, recommended carbohydrate intakes. Both studies were based on the same dietary standardisation protocol. Participants conducted the habituation phase prior to the one-week intervention. Daily carbohydrate intake (g·kg⁻¹·d⁻¹) was not significantly different between groups. Despite changes in protein intake within a group, there was no difference in protein intake between groups (Louis et al. 2016; Marquet et al. 2016). In Burke et al. (2017a), study participants were assigned to one of three versions of isocaloric diets with different macronutrient ratios, to test the efficacy of low-carbohydrate/high-fat diet on fat oxidation and performance during training in elite race walkers. Meal plans were individualised, prescribed per one kilogram of lean tissue mass and served within two grams of accuracy. Snacks were provided throughout each day and compliance with the prescribed diet was checked daily. As intended, there was no difference between daily energy (kJ·kg⁻¹·d⁻¹) and protein (g·kg⁻¹·d⁻¹) intake between groups.

Similarly, in this chapter but based on a different trained population, the provision of a standardised diet resulted in the same quantity of energy and macronutrient intakes, between groups. In addition to daily standardisation, energy and macronutrient
composition, the timing and distribution of each single EO was standardised since it has been shown that protein quantity, quality, distribution and timing of protein intake per EO alter MPS (Moore et al. 2011; Areta et al. 2013; Mamerow et al. 2014; van Vliet et al. 2015; Thomas et al. 2016; Maughan 2018).

To the author’s knowledge, this was a first intervention study where quantity, quality (source), timing, distribution and frequency of energy and nutrient intakes per single eating occasion were standardised for six days and reflected habitual dietary practices of resistance-trained male participants. The author recognises that the cost of high-quality dietary control, longitudinal daily collaborations with external food providers and compliance to a study protocol by free-living individuals could be major limitations of this approach over time. Besides, the record of habitual, 7-day weighed dietary intake and the physical activity record might be overly burdensome for participants when considering the training programme and activities of daily living. Additionally, the dietary standardisation protocol that is based on habitual food choices necessitates additional time to deliver a diet plan tailored for individuals’ needs, prior to the study. Moreover, at the time when the dietary standardisation was devised, Nutritics Ltd. (Ireland) did not provide the amino acid profile of protein sources. Hence, it could not be guaranteed that the planned EO provided the optimal amount of essential amino acids per EO. Furthermore, the quantity of leucine was analysed post-hoc. However, all meals provided the same quantity of protein (0.33 g·kg$^{-1}$) and the animal-derived protein was the main source of amino acids in all EO (except breakfast on Day 1). Lastly, despite high compliance to set standards, 55% ($N = 12$) of participants admitted that it was difficult to follow the prescribed dietary programme. Activities of daily living were the main reason (29%, 10 of 35 answers) supporting the identification of challenges in following the dietary programme for six days. On a daily basis, challenges in following recommended nutrient intakes due to a busy lifestyle among athletes, have been found by other researchers (Noronha et al. 2020).

8.8. Conclusions

In conclusion, this chapter provides detailed information about rigours, well-controlled dietary standardisation for short-term intervention studies (~7–14 days), participants’ compliance to provided EO and subjects’ reflection on the delivered dietary programme. The six-day dietary standardisation was strengthened by the consideration of habitual food choices of resistance-trained individuals and was optimised by
nutrient intakes based on dietary requirements peri-resistance training. The high compliance with the dietary standardisation limited the influence of nutrient intake patterns such as quantity, quality, timing, distribution and frequency within and between the studied groups. A control of dietary intakes for research purposes allowed researchers (Davies et al. 2019; Davies et al. 2020) to measure the test products’ efficacy on MPS, and to develop a better understanding of nutrient-exercise interventions. On one hand, despite high compliance to the provided meal plan, some participants found it difficult to follow on a meal-to-meal basis due to other commitments. On the other hand, participants appreciated the dietary programme and expressed interest in modifying their habitual intake patterns according to the energy and macronutrient quantities offered per EO, to the timing of EO peri-resistance training and to the distribution of EO throughout a day, after participation in the study. The author concludes that the proposed dietary standardisation is an effective approach in minimising the inter- and intra-subject variability of dietary practices within a nutrient-exercise type of intervention studies. The application of a PEN prescription in research design requires expertise and understanding of participants’ dietary and training patterns as well as their activities of daily living. The dietary standardisation here is based on collaboration with chefs and sports scientists and might prove cost-effective if it is well planned.

8.9. Further work

Further work should investigate compliance to the PEN standardised dietary intake in different designs of nutrient-exercise intervention studies in trained populations. Moreover, further research should investigate compliance to dietary replication as opposed to standardised diet prior to or during a research study. High compliance to dietary replication could provide a cheaper alternative than standardised diet provided in this study.
Chapter 9
General Discussion
9.1. List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>Competition day/s</td>
</tr>
<tr>
<td>EA</td>
<td>Energy availability</td>
</tr>
<tr>
<td>EO</td>
<td>Eating occasion/s</td>
</tr>
<tr>
<td>ET</td>
<td>Endurance training</td>
</tr>
<tr>
<td>PEN</td>
<td>Peri-exercise nutrition</td>
</tr>
<tr>
<td>RT</td>
<td>Resistance training</td>
</tr>
<tr>
<td>TD</td>
<td>Training day/s</td>
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9.2. Summary

Sport and exercise nutrition offers support for the attainment of goals related to health, training adaptation and competition performance. In pursuit of personalised and periodised nutrition for trained individuals and athletes, sport and exercise nutrition has advanced through improved methodology for dietary data collection and analysis, dietary standardisation and recommended dietary intake strategies (Magkos and Yannakoulia 2003; Jeacocke and Burke 2010; Phillips 2012; Thomas et al. 2016; Capling et al. 2017; Jeukendrup 2017; Burke and Hawley 2018; Maughan et al. 2018; Close et al. 2019; Stellingwerff et al. 2019). However, the dietary habits of trained populations frequently have been assessed for adequacy using procedures devised for non-trained populations. Hence, despite extant, research-based evidence concerning optimal nutrient intake specific to the exercise session and intent, it has not been established whether or not trained-individuals and athletes comply with these evidence-based recommendations. To date, only a few attempts have been made to assess dietary intake in direct proximity to exercise sessions (Burke et al. 2003; MacKenzie et al. 2015; Carr et al. 2019). Assessment of nutrient periodisation has been examined in the context of endurance events, primarily among runners and racewalkers, and has suggested that the application of a periodised nutrient approach in practice could be improved (Heikura et al. 2017; Heikura et al. 2018a). Examination of the methodology in these studies reveals limited assessment of habitual dietary practices in proximity to exercise sessions, which is attributed primarily to a lack of standardised methods to assess the patterns and time of nutrient intakes.

According to the research studies discussed in this thesis, to date, researchers have offered nutrient intake strategies tailored to an exercise session and its intent. However, subsequent attempts to analyse the adequacy of daily and per eating occasion (EO)
nutrient intakes in exercise nutrition does not currently facilitate assessment of time-, training-, and intent-tailored, best practice dietary guidelines. Evaluation of the application of these recommendations reveals over-attachment to traditional dietary assessment methods, insufficient digital platforms for data entry, and limited analysis methods that do not reflect the distinct dietary needs and nuances of EO (e.g. nutrient quantity, time) in proximity to an exercise session and an individual’s intent.

The author of this thesis proposes peri-exercise nutrition (PEN) approach as a means of addressing shortcomings in dietary assessment of trained populations. The author acknowledges that the proposed method is in need of refinement and further development through digital technology to encourage engagement and acceptance. However, to the author’s knowledge, no other work identifies shortcomings in current practices and models the potential application of PEN by analysis of current dietary practices peri-resistance training (RT) (Chapter 5) and peri-endurance exercise (Chapter 7). One outcome of these studies led to dietary standardisation, based on recommended intake (Chapter 4) and habitual dietary practices of resistance-trained males for use in a nutrient-exercise intervention study in young resistance-trained individuals (Chapter 8). The current status and challenges in adopting the PEN approach and the future work required to advance the PEN method are presented in Chapter 10.

9.3. Achievement of Aims
This section discusses outcomes of research chapters according to set aims and objectives of the studies.

9.3.1. Advancements to the Dietary Assessment in Trained Populations
Chapter 2 provided an overview of dietary assessment methods, including data collection, analysis and dietary recommendations. The PEN method of dietary assessment for trained populations was introduced. The PEN approach offers time-specific, exercise- and intent-orientated dietary assessment and optimised energy and nutrient intake practices for trained individuals within a weekly microcycle. An exercise session was proposed as a starting point to identify the duration of dietary analysis peri-training or competition (i.e. before, during, and after an exercise session), according to an individual’s intent and in agreement with the scientific evidence. The development of the PEN method included advancement to data collection and analysis
tools and considered the complexity of this approach. The implementation of the PEN assessment method was illustrated in the subsequent research chapters (i.e. Chapters 3–8).

9.3.2. Energy and Nutrient Intake Support for Resistance and Endurance Exercise
The aim of both Chapter 4 and Chapter 6 was to review the relevant literature and provide evidence-based energy and nutrient intake prescriptions to support the specific aims of the exercise sessions. Subsequently, this information was employed to assess the patterns and adequacy of energy and nutrient intakes by traditional and PEN methods of analysis. Chapter 4 discussed the energy and nutrient intake prescriptions in support of individuals’ health and associated with resistance training (RT) aims, e.g. muscle hypertrophy, strength gain and fat loss. This narrative review constituted the basis to evaluate the adequacy of protein intake in support of muscle hypertrophy and strength gain by a group of resistance-trained athletes in Chapter 5. Additionally, the scientific evidence demonstrated in Chapter 4 was employed to devise a dietary standardisation protocol in the nutrient-exercise type of intervention study in support of muscle protein synthesis in Chapter 8. In Chapter 6, the narrative review considered energy and macronutrient intake requirements in support of endurance exercise and stated the intent of the case study analysed. In line with the recommended strategies for carbohydrate availability peri–endurance exercise, the patterns of carbohydrate intake periodisation were examined in three endurance-trained individuals in Chapter 7.

9.3.3. Traditional Dietary and PEN Analysis of Resistance-Trained Individuals
The aim of Chapter 5 was to evaluate the patterns and adequacy of energy and/or nutrient intakes within a 7-day training microcycle in support of RT adaptation, i.e. muscle hypertrophy and strength gain in resistance-trained males. The analyses were completed using both traditional and PEN methods of dietary assessment. According to the traditional dietary analysis, results demonstrated that on average, subjects met daily protein intake for maximising muscle hypertrophy and strength gain, i.e. 1.6–2.2 g·kg\(^{-1} \cdot \text{d}^{-1}\) and 0.3–0.5 g·kg\(^{-1} \cdot \text{EO}^{-1}\) (Maughan et al. 2018; Moore 2019; Witard et al. 2019). On average, participants did not meet daily recommended carbohydrate intake [5–7 g·kg\(^{-1} \cdot \text{d}^{-1}\) on training days (TD) and 4–6 g·kg\(^{-1} \cdot \text{d}^{-1}\) on rest days (RD)] but met daily recommendations for fat (20–35% of total energy intake) (Thomas et al. 2016).
Median micronutrient intake values met daily recommendations (Institute of Medicine 2000a; 2011) (except for potassium, Vitamin D, Vitamin K and folates over 7 days).

Assessment of the adequacy of protein intake peri-RT demonstrated that the patterns of protein intake could be further improved in support of muscle hypertrophy and strength gain. The quantity of protein could be optimised for at least ~40% of all EO (N = 608), and distribution of EO for ~70% of all instances post-RT (N = 402). Concurrently, modification of EO distribution would require changes to the time of EO in proximity to RT. More attention should be given to promotion of pre-sleep feeding and either immediate pre- or post-RT feeding. The advocated optimised nutrient intake practices, in proximity to RT session, could maximise adaptive outcomes.

9.3.4. Case Study: Traditional Dietary and PEN Analysis of Endurance-Trained Individuals

Chapter 7 characterised patterns and the adequacy of energy and macronutrient intakes in support of endurance exercise goals within a weekly microcycle in a case study of three endurance-trained individuals. Dietary analyses were performed individually for each subject. Subjects reported an endurance exercise programme that included one or two endurance sessions per day and multiple exercise goals, within a weekly microcycle. Daily analysis of adequacy of energy availability (EA) (Loucks et al. 2011) and macronutrient intakes (Manore 2005; Burke et al. 2011; Thomas et al. 2016) within a 7-day recording, revealed that subjects met daily recommended EA and macronutrient intakes on 0–4 days.

The PEN analysis investigated patterns of carbohydrate availability peri-endurance training (ET) (Burke et al. 2018). The analysis of carbohydrate intake peri-ET revealed that two of three subjects tended to restrict carbohydrate intake (i.e. to 0–0.9 g·kg⁻¹·6h⁻¹) pre-ET for the first session on days of single or two ET sessions. The carbohydrate restriction was more evident within six hours before the first ET of the day, rather than between two ET or after the second ET session. High carbohydrate availability was required within four hours pre- and during competition events of > 90 minutes duration (Burke et al. 2011). One subject who reported a competition event of > 90 minutes duration met the carbohydrate intake requirements before and during the event. However, daily carbohydrate intake on competition day (CD) and 48-hour
carbohydrate loading protocol pre-event, were not met for the same competition event. The analysis of adequate carbohydrate and protein intake within four hours post-RT was not required because the duration of a post-recovery phase was not restricted (Burke et al. 2011). However, the patterns of carbohydrate and protein intake in the first four hours post-RT was reported in Chapter 7. Additionally, the adequacy of protein intake and pattern of carbohydrate intake were evaluated for one RT session in support of the muscle hypertrophy and gain in strength by one subject. Finally, the PEN decision process of nutrient intake analysis was demonstrated using the example of multiple exercise sessions and an individual’s goals for one day.

9.3.5. PEN in Research: An Example of Dietary Standardisation

Dietary standardization is a viable opportunity to decrease variation in dietary intakes among individuals in research studies (Jeacocke and Burke 2010; Close et al. 2019). The aim of Chapter 8 was to devise a standardised approach to meal plans, which (1) represented habitually consumed foods and beverages of the resistance-trained individuals; (2) complied with dietary recommendations; and (3) met participants’ foods preferences, for use in a nutrient-exercise type of intervention study. The implemented meal plan considered nutrient intakes, type, quantity, quality (source), time peri-RT, distribution and frequency of EO on a daily basis. High adherence to daily quantity of energy and macronutrient intakes [100 (99–100)%], frequency [100 (100–100)%], time and distribution [97 (93–100)%] was observed. There were no differences in nutrient intakes between three tested groups over six days. Results demonstrate that the proposed example of dietary standardisation was effective in assuring nutrient intakes according to prescription during a research study. Moreover, the high adherence to the standardised diet assured that the observed changes were not biased due to variation in dietary intake patterns among participants.

9.4. Synthesis of Findings

In this section, a synthesis of findings for dietary analysis and standardisation for resistance-trained and endurance-trained individuals is presented according to traditional and PEN methods of dietary analysis.

Traditional method of dietary analysis

- Resistance-trained individuals met average daily recommendations for protein and fat intakes, and frequency of EO. Daily recommended intake
for carbohydrate on TD and RD, potassium, Vitamin D, Vitamin K and folates analysed within a 7-day recording, were not met by resistance trained individuals.

- Resistance-trained individuals met average protein intake per main EO but not per snack.
- Three endurance-trained individuals complied with daily EA and macronutrient intake requirements for 0–4 days for each variable, within a 7-day record.

PEN method of dietary analysis

- Pre- and during RT, as well as one-hour, pre-bedtime protein intake practices were suboptimal among resistance-trained individuals.
- Within 24 hours post-RT, protein quantity per EO (~44%) and protein intake distribution (~70%) could be improved for resistance-trained individuals. The improvement of protein intake quantity and distribution would necessitate amendments to time of nutrient intakes peri-RT but not necessarily to frequency of EO.
- Endurance-trained subjects did not tend to withhold carbohydrate intake peri-ET when training twice a day or pre-ET when training once a day.
- Within four hours pre- and during endurance competition of >90 minutes duration, carbohydrate intake was met. However, the 48-hour carbohydrate intake loading protocol was not met before this event.
- Six-day dietary standardisation was a successful tool in controlling energy and macronutrient intakes (~100%) and distribution (~97%) among resistance-trained participants.

9.5. Practical Applications
The PEN approach offers advancement and refinement of dietary intake data collection and analysis for exercising and trained populations. The approach allows for analysis of adequacy and patterns of time-specific nutrient intake practices in proximity to exercise sessions and specific to an individual’s intent. The details of PEN analysis (e.g. optimal pattern of nutrient intake, duration of analysis peri-exercise) tailored to training or competition events and intent are informed by scientific evidence. The output of the PEN analysis may find its application in the following areas:
Practitioners may refine sub-optimal dietary intake of trained individuals based on their habitual practices to support trained individuals’ goals. The optimisation of nutrient intakes may be implemented only for suboptimal intake without modifying EO, which meet the recommended intake peri-training and peri-competition.

Researchers may propose dietary standardisation that considers habitual dietary intake patterns peri-exercise of research participants, to support high adherence to a research protocol.

Comprehension of suboptimal dietary practices in proximity to exercise sessions among trained individuals may create opportunities for development of new food products to correct suboptimal dietary practices at particular time points.

9.6. Concluding Statement

The traditional method of dietary assessment does not evaluate dietary intake adequacy and patterns in proximity to exercise sessions and individuals’ intent. Hence, the nuances of suboptimal nutrient intake patterns might be concealed and thus, may compromise the attainment of training and competitive goals. The PEN approach addresses this omission and offers researchers and practitioners an advanced method of dietary data collection, analysis and prescription for trained populations. Furthermore, the PEN approach offers analysis of energy and nutrient intakes (type, quantity, timing, distribution and frequency) specific to training and competition and individuals’ intent, within a weekly microcycle. Dietary standardisation devised in line with the PEN approach considers time-, exercise- and intent-tailored dietary recommendations; represents habitually consumed foods and beverages; and meets participants’ foods preferences to assure subjects’ high compliance to the standardised dietary protocol. Nevertheless, the PEN approach might be considered as a complementary advancement to the traditional method of dietary assessment. The author acknowledges the complexity of the approach (i.e. data collection, coding and analysis) and discusses the futures efforts necessary to overcome these limitations, in Chapter 10. Further research is warranted to digitalise data collection and to automate analysis of the PEN approach since this method might provide valuable advancement to the traditional dietary assessment method in practical and research settings.
Chapter 10
Summary of the Peri-Exercise Nutrition Approach: Current Status, Challenges and Future Work
10.1. List of Abbreviations

EO  Eating occasion/s  
ET  Endurance training  
MPS  Muscle protein synthesis  
PEN  Peri-exercise nutrition  
RT  Resistance training  

10.2. Abstract

This chapter summarises the current status, challenges and further work that is required to improve the peri-exercise nutrition (PEN) approach. The process involves four steps that relate to data collection, data coding, data output file and analysis, and to the availability of evidence-based recommendations to conduct PEN assessment. The last section sums up the steps for and outlines the dietary assessment process advanced by the PEN method. Despite the promising application of the PEN approach, further development of technology should allow for digital data collection to decrease the time needed for data recording by participants of research studies and for data coding by nutritional professionals. Additionally, advancements to nutrition analysis software are needed to digitalise data output files according to dietary analysis requirements that correspond with training sessions, competition events and individuals’ aims. Last but not least, further research is needed to provide time-, training- and intent-specific dietary intake strategies for trained individuals in support of their aims.

10.3. Aim

This chapter aims to summarise the PEN approach in three areas, the current status of the PEN approach, challenges identified in its development and application, and recommended future work to improve it.

10.4. Data Collection

10.4.1. Current Status

Data were collected using a 7-day, weighed dietary record together with a physical activity log. Participants were provided with a paper or electronic (Microsoft Excel 2016) copy of the record. The 7-day dietary record was used since it was shown to be more accurate than estimated and more precise than shorter methods, among athletic populations (Braakhuis et al. 2003; Magkos and Yannakoulia 2003). For trained and athletic populations, a 7-day dietary data collection recording provides detailed
information about individuals’ dietary patterns and exercise programmes within a weekly microcycle, including training and rest days within one phase of the season.

10.4.2. Challenges
The duration of a 7-day record was suitable for data recording of trained individuals when the dietary record was analysed using a traditional dietary assessment approach or when an exercise session was reported within the first six days of an exercise programme. In the proposed PEN assessment in Chapter 5, protein intake was examined 24 hours post-resistance training (RT). In this study, all 37 participants started their data record on Monday (Day 1) and completed it on Sunday (Day 7). Because two participants trained on Day 7, the dietary intakes for these two RT sessions were excluded from analysis due to incomplete datasets (See Chapter 5, Figure 8). This example shows that when a training session is performed on Day 7, the dietary record could be extended to eight days. The record extension of one day would allow the analysis of 24 hours post-RT, or post-endurance competition when another competition occurs within 24 hours and recovery time is restricted.

The physical activity log used in this doctoral thesis with a group of resistance-trained individuals did not capture information about the intensity of RT performed, the percentage of one repetition maximum and whether an RT was performed to failure. The addition of this information would allow assessment of the exercise energy expenditure using Ainsworth’s Compendium of Physical Activities (Ainsworth et al. 2011). Subsequently, this information would enhance analysis of adequacy for total energy expenditure and daily carbohydrate requirements, i.e. within a traditional dietary assessment approach. In the study involving resistance-trained male subjects, in Chapter 5, the carbohydrate requirements were proposed for training and rest days. These recommendations were given based on the mean duration of all types of training sessions performed within a weekly microcycle (i.e. > 1 hour). In accordance with Thomas et al. (2016), carbohydrate intake was set at 5–7 g·kg⁻¹·d⁻¹. The daily required carbohydrate intake on rest days was set for each participant according to recommended energy availability of 45 kcal·kg⁻¹ of fat free mass per day.

The 7-day physical activity log and guidelines were improved after data collection completion by resistance-trained individuals. The physical activity log was developed as a separate log in the Microsoft Excel 2016 file (Appendix 2) and used by endurance-
trained subjects instead of a paper copy. The information about training intensity was assessed with the Borg Rating of Perceived Exertion Scale (Borg 1982; Foster et al. 2001). The additional information of whether RT was performed to failure was added. Consequently, following the changes in the physical activity log, the 7-day weighed dietary record and guidelines (Appendix 9) were amended. The amendments in the dietary record related to the physical activity section. Endurance-trained subjects in the subsequent research study (Chapter 7) used both amended dietary and physical activity logs.

10.4.3. Future Work

Future work relates to the digitalisation of dietary intake records. Participants recruited to the intervention study (Chapter 8), were asked how to improve the data collection process. Of the 23 participants, 48% ($N = 11$) of individuals suggested that a digital application would improve the record. Thus, the digital application could allow recording the information that is captured in dietary and physical activity logs. Moreover, an application should include the information from national food databases and the Ainsworth’s tables to quantify the data file output. The automated check of data completeness and correctness could shorten the time of data file preparation for analysis. Finally, the output file settings should allow for data exporting in a suitable format for traditional dietary analysis, but also for the PEN analysis when dietary intake evaluation is supported by scientific evidence in proximity to a training or competition event.

In this research project, participants recorded detailed dietary intakes and exercise programmes. Afterwards data were coded into the nutrition analysis software by the author. Thus, understanding of data entry using digital technologies, together with food composition databases, was not required from participants. Digital data recording by participants would require their familiarisation with available food composition databases and understanding of coding

- food ingredients, ready to eat food products, beverages and dietary supplements,
- dietary products with different macronutrient content as well as fortified options of the same product, and
- dietary ingredients that are not available in databases.
The potential use of the proposed application should be preceded by its validation (Capling et al. 2017).

10.5. Data Coding

10.5.1. Current Status
Dietary data were coded into the Nutritics Ltd. (Ireland) software according to the developed, standardised operating procedure (Appendix 3). The data entry included food, fluids and dietary supplement intakes under the revised eating occasion (EO) descriptors (described in Chapter 2 Section 2.9) that have been traditionally used in dietary assessment (Burke et al. 2003; Erdman et al. 2013; Carr et al. 2019). The data entry fields for every EO, 0 kcal fluids and 0 kcal dietary supplements were added to capture the information related to date, time, type of day, phase of season, descriptor, and location of food, beverage and dietary supplement preparation or purchase. In the PEN assessment, analysis was based on the actual time of nutrient intakes, so EO descriptors were not used in the PEN data coding and analysis. Type and time of training sessions and competitive events were coded in the software. Other characteristics of training sessions or competition events were available in the additional excel file. The wake-up times and bedtimes were entered into a separate excel file and added to a dietary data output file from the software.

10.5.2. Challenges
Current dietary data and general information about the physical activity log were available in the software output file. Detailed information about exercise sessions, other than type and time of exercise sessions, was available in an additional Microsoft Excel 2016 file, together with wake-up time and bedtime data. Dietary and exercise data available in two different files required incorporation of the information into one Microsoft Excel 2016 file, which was then set up for traditional and PEN data analysis.

10.5.3. Future Work
Future work requires the addition of training and competition information, individuals’ intent, and wake-up times and bedtimes into additional custom fields in the software. This information should be added for each recorded day. The addition of these custom fields would allow for data export in one single output file. The challenges identified in data entry and output could also be solved by using software that can allow data
export in a format suitable for analysis, e.g. analysis of protein intake pre-/post-RT only, or carbohydrate intake between ET sessions.

10.6. Data Output Files and Analysis

10.6.1. Current Status

Nutritics Ltd. (Ireland) software facilitates a standard output file, which allows for comparison of nutrient intakes versus recommended daily intakes. Within the PEN approach, time, training and intent-specific analysis necessitated further development of Nutritics Ltd. (Ireland) standard output files. The custom-designed fields tailored to the PEN analysis were developed to advance the data output files from the software. The custom-designed fields were filled with the information recorded in a dietary records and exercise logs (i.e. date, type of day, time of EO, place of EO preparation, phase of a season, type and time of an exercise session). Further data about an individual’s exercise programme, intent, wake-up times and bedtimes were accessible in the additional excel file. The data output file was set for the PEN analysis using pivot tables, available text, logical, statistical, and Visual Basic for Applications functions (Microsoft Excel 2016) (see Chapter 2, Section 2.10.1.4.).

10.6.2. Challenges

Originally, the Nutritics Ltd. (Ireland) software did not facilitate nutrient intake analysis specific to a type of training session in a time-dependent manner. Because of this limitation, the author set up the output of dietary intakes of trained individuals by placing training sessions or competitive events at the core of the analysis. This adjustment had to be made for each participant to investigate their dietary intake peri-exercise. The complexity of the analysis can be seen in Chapter 5, where nutrient intakes were analysed up to 24 hours post-RT. The extension of the analysis beyond daily analysis had to account for post-RT phases of different durations due to variations in individuals’ practices. For example, the post-RT phase could not be examined up to 24 hours post-RT in 48% of scenarios \((N = 118)\), because another RT session was performed within the 24 hours of dietary intake examined. Similarly, dietary analysis one hour before RT was not examined for 27% of RT sessions \((N = 118)\) that began within 24 hours of the post-training phase of a previous RT session. Specific to endurance training (ET), the PEN analysis of nutrient intake patterns in different timeframes also required adjustment of the output files (see Chapter 7).
Working collaboratively with the software developers at Nutritics Ltd. (Ireland) during the course of this doctoral work, the entry fields for data coding were added in the nutrition analysis software. However, at the time of this project, further software advancements to facilitate analysis of protein quality were not feasible. Hence, the amino acid quantity per EO was not assessed. The presented results cannot assure that habitual essential amino acid and leucine intakes per EO were optimal to maximise protein synthesis post-RT (Churchward-Venne et al. 2012a; Churchward-Venne et al. 2014).

10.6.3. Future Work
Future work on the existing software or new software is required to provide output files, where the time of nutrient intakes are shown in proximity to exercise sessions. This option should allow for choosing the nutrient of interest and duration of analysis in proximity to specific training sessions. During dietary analysis, the output file should allow for consideration of the proximity of the adjacent exercise session, its characteristics and goals. The available summary of dietary intake, goals and characteristics of concurrent exercise sessions within the analysed phase could advise a practitioner if dietary recommendations peri-exercise should be adjusted due to the proximity of another training session or competition event (Coffey and Hawley 2007). Moreover, the advancement of the data output file of amino acid content would allow for further investigation of diet quality. For example, the information about amino acid content in food products could be sourced from the published food composition databases and journal papers, and then coded into the software.

10.7. Evidence-Based Recommendations

10.7.1. Current Status
There is growing evidence of the legitimacy of considering the time of nutrient intakes in proximity to an exercise session (Jeukendrup 2017; Kerksick et al. 2017; Burke and Hawley 2018). The current prescribed and considered optimal nutrient intakes peri-exercise in support of an individual’s goals is mostly derived from research studies that investigated an effect of the single nutrient, not nutrients as a part of a food matrix.

10.7.2. Challenges
According to the dietary considerations in Chapter 4, there is a paucity of data to address the efficiency of protein intake between 12 and 24 hours post-RT in resistance-
trained individuals. However, the paradigm of dietary analysis up to 24 hours post-RT is based on evidence that protein feeding up to 24 hours post-RT was shown to result in greater MPS response than protein intake at rest (Burd et al. 2011; Churchward-Venne et al. 2012b). Additionally, less is known about the required amount of carbohydrate intake to optimise net protein balance when protein intake is suboptimal (Aragon and Schoenfeld 2013). Hence, the amount of carbohydrate intake peri-RT was examined but the adequacy of intake was not compared to a reference value because this evidence is limited.

Specific to ET, the manipulation of carbohydrate intake availability may promote endurance adaptation and exercise performance (Jeukendrup 2017). However, the optimal recommendations of carbohydrate intake in periods of training with “low” carbohydrate availability have not been yet specified (Impey et al. 2018). Therefore, in Chapter 7, patterns of carbohydrate periodisation were reported and discussed, but the quantified adequacy of carbohydrate intake in proximity to endurance exercise was not evaluated (for details see Table 32). Analysis of the adequacy of nutrient intakes may not always be achieved due to evidence paucity of dietary recommendations peri-exercise. Thus, the practice of PEN analysis may improve in parallel with the growing scientific-based evidence of optimal nutrient intakes peri-exercise.

The majority of research investigated the effect of isolated nutrient intake on exercise adaptation or performance. In the ecologically valid environment, an individual diet consists of food products or dishes that do not provide only one nutrient, but instead are based on nutrient co-ingestion, including vitamins and minerals. For example, the effect of protein-rich whole foods on RT adaptation, preliminarly has been shown to result in greater muscle protein synthesis than an isolated protein source from a food matrix (van Vliet et al. 2017; Burd et al. 2019). Another example that investigated the co-ingestion of carbohydrate intake with another macronutrient showed no difference in glycogen restoration over 24 hours in any of three, energy-matched conditions (Burke et al. 1995).

10.7.3. Future Work
Further research is needed to clarify the nutrient intake requirements specific to an exercise session, and that would support an individual’s goals. More research is needed to investigate optimal quantity, quality, time, frequency, and distribution of nutrient
intakes in support of training adaptation and exercise performance. Moreover, more prominence should be given to the effect of nutrient co-ingestion on exercise outcomes. Close et al. (2019) proposed the nine-stage decision-making process to judge if the available nutrient-exercise research is feasible to be translated and implemented into practical settings. Doubtlessly, all nine steps (e.g. participants’ characteristics, dietary and exercise control, and time of intervention) should be taken into consideration at the time of planning research design, to make the outcome feasible to apply in practical settings.

10.8. Summary of the PEN Approach

10.8.1. Current Status

Figure 14 integrates the individual steps of the dietary assessment process advanced by a PEN approach and provides examples of outcomes. Additionally, a decision tree presented in Figure 3 in Chapter 2 provides guidelines on how to conduct the PEN analysis in the presence of multiple exercise sessions and goals.

10.8.2. Challenges

The challenges of adopting the PEN approach include

- data collection using electronic devices or further customisation of nutrition analysis software, to allow for data export in a single output file,
- data analysis due to the necessity of setting up every dataset for peri-exercise analysis, and
- limited information about dietary recommendations for trained individuals, considering food first approach and nutrient interactions.
Figure 14 Flowchart of dietary assessment advanced by the PEN approach

Note. The aim of dietary assessment might be informed by a research question or goals of trained individuals in applied work.
10.8.3. Future Work

Future work should address the

- development of digital technology (e.g. mobile phone application) for data collection, which should be valid, robust and comprehensive. The collected information should be sufficient to examine adequacy against a set of recommendations.

- complement food databases with the information required for analysis of protein quality.

- development of software functionalities that will produce the output file allowing for investigation of nutrient intakes (i.e. quantity, quality, time, distribution and frequency) in proximity to training sessions and competitive events.

- investigation of optimal nutrient intake patterns specific to type of exercise session, individual training status and an individual’s intent, including the whole food matrix.
References


American College of Sports Medicine; American Dietetic Association; Dietitians of Canada (2000) 'Joint Position Statement: nutrition and athletic performance. American College of Sports Medicine, American Dietetic Association, and


Bettonviel, A.E., Brinkmans, N.Y., Russcher, K., Wardenaar, F.C. and Witard, O.C. (2016) 'Nutritional status and daytime pattern of protein intake on match, post-


Scheers, T., Philippaerts, R. and Lefevre, J. (2012) 'Variability in physical activity patterns as measured by the SenseWear Armband: how many days are


Stellingwerff, T., Maughan, R.J. and Burke, L.M. (2011) 'Nutrition for power sports: middle-distance running, track cycling, rowing, canoeing/kayaking, and


Appendices

Appendix 1 7-day weighed dietary intake record guidelines

Food, Fluid and Dietary Supplement

Diary Guidelines
Food, Fluid and Dietary Supplement Diary Guidelines Content

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Food, Fluid and Dietary Supplement Diary
Guidelines

In order to measure your nutritional intake over the seven days, it is required that you fill out a Food, Fluid and Dietary Supplement Diary as accurately as possible to give the most detailed description of your dietary intake. The following pages will provide information and guidelines on how to fill out the Food, Fluid and Dietary Supplement Diary correctly.

Important points to note

- In order to obtain an accurate representation of your dietary intake, it is essential that you do not alter or change your diet in any way from what you consider is your regular diet, for the duration of the seven days.

- Do not write down what you think the researchers would want to see. All information is confidential, and no person’s diet will be ‘judged’ by the researchers.

- Be as accurate and honest as possible in your recording of food and fluid intake over the seven days (see guidelines that follow).

- All food and fluid intake should be recorded on the Food, Fluid and Dietary Supplement Diary.

- All medications and dietary supplements, e.g. vitamin and mineral supplements/sports supplements should be recorded on the Food, Fluid and Dietary Supplement Diary.

How to fill out the Food, Fluid and Dietary Supplement Diary

Please fill in your participant ID (if you know it, do not write down your name), your date of birth, the recording date, the recording day, your wake-up time and bedtime and how you feel that day. Please fill in your body mass and height and provide units for values you report.
The subsequent sheets are required to record your ID Code, the recording day, the recording date, the wake-up time, bedtime, and how you are feeling.

<table>
<thead>
<tr>
<th>PARTICIPANT ID</th>
<th>RECORDING DATE (DD/MM/YYYY)</th>
<th>RECORDING DAY</th>
<th>ARE YOU FEELING</th>
<th>IF UNWELL DID THIS AFFECT EATING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26</td>
<td></td>
<td>WELL</td>
<td>YES</td>
</tr>
</tbody>
</table>

**Explanation of column terms**

**Time**
Record the time each meal/snack was eaten and beverage was drunk, e.g. 07:00, 12:30, 13:27, 19:15. If recording using a 12-hour clock method, please state the time followed by am/pm.

**Meal Type**
Describe what type of meal or beverage this is. Examples may include but are not restricted to Breakfast, Lunch, Dinner, Snack, Supper, Drink, Pre-Exercise, During Exercise, Post Exercise, Alcoholic beverage, Non-alcoholic beverage etc.

**Place**
Record the place each meal/snack and beverage was prepared or bought, e.g. home, work, university, friend’s house, restaurant, fast food, take away, pub, café, etc. If you were eating this meal or snack before, during or after a training session or match, please also note this here. If you train or compete that day, write it down here briefly as well, e.g. Training – cycling 14:00-15:00.

**Food or Drink Description and Brand Name**
Describe the food, e.g. wholegrain or white or wholemeal toast Brennans Bread or Irish Pride; chicken stir-fry, yoghurt Greek style, rashers back bacon, beef mince 18% fat, etc. If a food label states whether it is low-fat, light or fortified with vitamins, minerals, no added sugar, whole, semi-skimmed or skimmed product, it is important to state these details also (e.g. Avonmore pasteurised low-fat milk instead of just milk or even low-fat milk).

If a meal consists of more than one ingredient (see the example of chicken stir-fry, below), first record the name of a dish, e.g. chicken stir-fry and then list the individual constituents of the meal.

Example 1: Bowl of porridge: porridge oats, milk (type) and anything added, e.g. honey/blueberries/seeds, etc.

Example 2: Chicken stir-fry: chicken breast, red pepper, onion, mange tout, leek, carrots, noodles and olive oil.
Any multivitamin and mineral supplements must be recorded, and their name and the brand name also recorded, as well as if they have been taken with something else (e.g. 1 tablet of 1000 IU Vitamin D3 with 200ml orange juice).

Any sports supplements and shakes must also be recorded, e.g. Kinetica or High 5 power bar recovery or protein shake. If recording a sports supplement, other ingredients consumed with a supplement should be recorded as well, for example, protein powder or shake (type, i.e. whey or casein; concentrate, isolate or hydrolysate, brand, dose) and milk (type, e.g. semi-skimmed, brand, quantity) or water.

Record the brand name of products where applicable, e.g. for the Vitamin D3 supplement mentioned previously in this column you would record the brand name, such as Spatone, Holland and Barrett, etc.

In the case of milk, you should record a brand name such as Avonmore, Golden Vale, etc.

**Cooking method**

It is essential that cooking methods are recorded accurately and listed here, e.g. fried, boiled, poached, microwaved, oven cooked, toasted, etc.

**Quantity**

You will be provided with electronic weighing scales for the seven-day recording or you will be asked to use your own scale. Individual ingredients of a meal should be weighed (preferably after cooking) and their weight recorded in grams (g) millilitres (ml). For example, if making a sandwich, the bread, butter/spread, meat or filling, and vegetables should be weighed separately and recorded separately.

Wrappers of less popular food items should be photographed. The photographs should include the name, brand, list of ingredients and the nutritional information of a product. If unsure about any item, please keep the packaging and wrappers and contact us. Please provide us with photographs or the original packaging when returning a diary in person or via e-mail. Each photograph’s name should include your ID Number, the date (DD-MM-YYYY), the recording day (1-7) and time of intake (use the 24 hour clock). See the following example: M001_01-01-2020_1_0820. (ID Number_date_recording day_time of consumption).

If cooking and eating a full pizza, it is sufficient to record the weight and ingredients of the pizza stated on the box.
The quantity of milk added to porridge or breakfast cereals should also be measured independently from the cereal. To weigh the milk,

1. Place a bowl on the weighing scales
2. Press the Tare button to bring it to 0
3. Place the cereal in the bowl
4. Record the weight of the dry cereal in your diary
5. Press the Tare button once again to bring it back to 0
6. Pour in the milk
7. Record the weight of the milk in your diary

Similarly, for butter or spread on a slice of bread, the bread should be weighed, the scales tared, the bread buttered and then re-weighed, with the difference recorded as the weight of the butter or spread.

The quantity of water consumed should also be recorded in the Food, Fluid and Dietary Supplement Diary.

**Quantity left over**

If you do not eat all of a particular meal/snack, the remaining quantity should be weighed and recorded in this column.

**Any Comment or Additions at cooking or Eating (dressings, condiments, herbs)**

Use this section to add any important notes/comments that you feel may be important. Please state here if any dressings, condiments or herbs were added during food preparation, e.g. Cooking method: Boiled in unsalted/salted water, any comment: 3 g of sea salt added, etc.

**Additional space on the next sheet**

Please use this space to detail:

1. Any composite dishes, homemade recipes and ingredients use, that you might have consumed throughout the day, e.g. lasagne, stew, homemade bread. This sheet can also be used to attach food packaging or wrappers, which are difficult to describe, e.g. frozen vegetable mix, products fortified in vitamins or minerals.
2. Any medication, vitamin, mineral or herbal supplements that you have taken throughout the day. If listing medicines or dietary supplements, please include
product name, manufacturer, dose, time of intake and food consumed or fluids drunk during their intake.

3. Any exercise that you have done throughout the day. Please include time, duration of the exercise and express any weight lifted in kilograms and/or as a % of your 1RM where appropriate.

FAQs

1. **What about pre-packaged foods?**
   In the case of pre-packaged, over-the-counter foods that you are unsure of how to record, e.g. a pre-packaged sandwich, it is important to keep the food packaging and nutrition labels and pin to the correct day in your Food, Fluid and Dietary Supplement Diary or send a photo via email.

2. **What about foods bought in a deli/sandwich bar?**
   In the case of foods such as a deli sandwich that is made on the spot: record the individual ingredients, type of bread, butter or mayonnaise. If possible, record the total weight of the sandwich/roll-wrap/bagel/bap and take the nutrition information with you. Take pictures, print and pin to the correct day in your Food, Fluid and Dietary Supplement Diary or send via email.

3. **What about takeaway foods?**
   In the case of consuming takeaway food, record the specific meal you have ordered and take the nutrition information with you. Take a picture, print and pin it in your Food, Fluid and Dietary Supplement Diary in the correct day. Named pictures can also be sent via e-mail. The picture name should include your **ID Number, the date (DD-MM-YYYY), the recording day (1-7) and time of intake (use the 24 h clock) as the following example M001_01-01-2020_1_0820. (ID Number_date_recording day_time of consumption).**

   **Note:** If you are unsure about a particular food, ensure that you either take a picture of the food and any packaging/nutrition labelling or take the packaging and attach it to the appropriate day in your Diary. Record the weight of consumed food. Pictures of the food labels-packaging should be printed and attached to the appropriate day in your diary. Named pictures can also be sent via e-mail. The picture name should include your **ID Number, the date (DD-MM-YYYY), the recording day (1-7) and time of intake (use the 24 h clock) as the following example M001_01-01-2020_1_0820. (ID Number_date_recording day_time of consumption).**
intake (use the 24 h clock) as the following example M001_01-01-2020_1_0820. (ID Number_date_recording day_time of consumption).

If there are any queries about the Food, Fluid and Dietary Supplement Diary, please do not hesitate to contact Marta Kozior (PhD Researcher in Sport and Exercise Nutrition) by e-mail (deleted from this appendix) or by telephone (deleted from the Appendix).
### Example of how to correctly fill out the Food, Fluid and Dietary Supplement Diary

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<tbody>
<tr>
<td>06:00</td>
<td>Drink Coffee</td>
</tr>
<tr>
<td>06:00</td>
<td>Work</td>
</tr>
<tr>
<td>09:00</td>
<td>Pre-workout Gym</td>
</tr>
</tbody>
</table>

#### 10:00-16:00 TRAINING (see table)

<table>
<thead>
<tr>
<th>11:00</th>
<th>Eating Back, Friend’s House</th>
</tr>
</thead>
</table>

| 16:30 | Dinner Home |

#### Food & Fluids

- **Breakfast**: Whole grain cereal, fruit, and milk
- **Lunch**: Grilled salmon, steamed vegetables, rice
- **Dinner**: Grilled chicken, quinoa, steamed broccoli

#### Hexagon

- **Morning**: 800 ml water
- **Afternoon**: 1200 ml water

#### Data Collection

- **Self-reported body mass**: 80.6 kg
- **Self-reported height**: 178.1 cm

*Note: All entries are approximate and subject to variation.*
Appendix 2 Physical activity log guidelines

**Physical Activity Log (PA Log) Information Sheet**

The Physical Activity Log is the file created in Microsoft Excel to help you record your physical activity from each place without carrying a paper version with you, e.g. at the gym or swimming pool. Everything that you need to use is accessible on your mobile phone and e-mail inbox.

**Directions for use**

- The Physical Activity Log was created to record information about all types of training sessions.
- Record your endurance, skill, power or team training sessions in one worksheet and resistance, mobility and rehabilitation sessions in the second worksheet. Please complete worksheets according to their intended use.
- You will record your physical activity during seven consecutive days. If you were asked to record your dietary intake, then please record all information concurrently, i.e. the first day (Monday) of food and fluid intake is also the first day of your physical activity record (Day 1 Monday, etc.).

Please record the following information about your training:

**A. Endurance, skill, power, team training sessions and competition events**

a) **Primary sport discipline.** Please choose your current primary sport discipline from the drop-down menu or if other, specify.

![Endurance, Skill, Power, Team Training Session](image)

b) **Recording day number.** Please choose from 1 to 7 from the drop-down menu, where 1 is the first day, and 7 is the last day.
c) **Recording day.** Please choose the appropriate recording day from the drop-down menu from Monday to Sunday. We will always ask you to start recording your data on Monday and to finish on Sunday.

d) **Recording date** in this format: DD/MM/YYYY.

e) **Type of day.** Please choose the appropriate type of day from the drop-down menu. If it is your rest day, please choose Rest Day. When you choose the Rest Day option, it will be the last field that you need to complete for that day. If you choose Training Day or Competition Day, you will complete the remaining fields in that table.
f) **Number of training session or competition event during that day.** Please choose number of training session or competition event from a drop-down menu.

![Number of training session or competition event](image)

**g) Type of training session or competition event.** Please choose the appropriate type of training session or competition event from the drop-down menu.

![Type of training session or competition event](image)

**h) Start time and end time.** Please enter the time when you start your training session and when you finish it. Please input time in HH:MM format (24-hour format only, from 00:00 to 23:59).

![Start and end time](image)
i) **The overall duration of training session or competition event.** Please enter the total time of your training session or competition event in hours and minutes.

![Duration Input](image)

j) **Distance run, swum, cycled if applicable (km).** Please enter the distance covered during your training session or competition event. Use decimal values where applicable.

![Distance Input](image)

k) **RPE of training session or competition event.** The Borg Rating of Perceived Exertion Scale allows you to self-estimate the expended effort of your training. Notice that there are different RPE scales in use. For the purpose of our study, we will use Borg’s 0-10 RPE scale, where 0 means Rest and 10 means Maximal. Please assess your RPE 30 minutes after the end of your training session or competition event. You can find the RPE scale in the first page of your PA Log, called: Borg’s RPE Scale. The scale was also enclosed as an independent attachment in the e-mail that you received. Lastly, if you meet with a researcher at the University of Limerick, you should also receive the Borg’s scale during your appointment.
l) **Goals of training session or competition event.** Please choose up to three goals of your training from the drop-down menu. If your goal is not listed, please use the Other option and specify the goal. You can choose up to three goals. Please rate your goals from 1—the most important, 2—very important, to 3—important.

   ![Drop-down menu for training goals](image)

   - 1 Rest, very easy
   - 2 Easy
   - 3 Moderate
   - 4 Somewhat hard
   - 5 Hard
   - 6
   - 7 Very Hard

m) **The next question refers to the periods of high intensity within your training session or competition event.** Please choose Yes or No from the drop-down menu. If you choose No that is all we ask you. If your answer is Yes, please refer to the last two questions.

   ![Question regarding high-intensity periods](image)

   - Yes
   - No

n) **The overall duration of high-intensity exercises within a training session or competition event (min).** If your answer was Yes for the previous question please state the overall duration of high-intensity phase in minutes. Use decimal values where applicable.

   ![Input field for high-intensity duration](image)
o) **Distance run/swum/cycled at high intensity (km).** Please enter number of kilometres run, swum, cycled at high intensity. Use decimal values where applicable.

B. **Resistance, rehabilitation and mobility training session or competition event**

a) **Primary sport discipline.** Please choose your current primary sport discipline from the drop-down menu or if other, specify.

b) **Recording day number.** Please choose from 1 to 7 from the drop-down menu, where 1 is the first day and 7 is the last day.
c) **Recording day.** Please choose the appropriate recording day from the drop-down menu from Monday to Sunday. We will always ask you to start recording your data on Monday and to finish on Sunday.

![Recording day dropdown menu]

**Recording date** in the format: DD/MM/YYYY.

c) **Recording date** in this format: DD/MM/YYYY.

![Recording date error message]

f) **Type of day.** Please choose the appropriate type of day from the drop-down menu. If it is your rest day, please choose Rest Day. When you choose the Rest Day option, it will be the last field that you need to complete for that day. If you choose Training Day or Competition Day, you will complete the remaining fields in that table.

![Type of day dropdown menu]

g) **Number of training session or competition event during that day.** Please choose number of training session or competitive event that day from the drop-down menu.

![Number of sessions dropdown menu]
h) **Type of training session or competition event.** Please choose the appropriate from the drop-down menu.

i) **Start time and end time.** Please enter the time when you start your exercise session and when you finish it. Please input time in HH:MM format (24-hour format only, from 00:00 to 23:59).

j) **The overall duration of training session or competition event.** Please enter the total time of your training session or competition event in hours and minutes. Use decimal values where applicable.
k) **Profile of exercises during your training session** Please complete fields regarding name of the exercises, number of sets and repetitions, weights lifted (kg), duration of rest between sets. If you repeat the same exercise in multiple sets but with different number of repetitions, weights lifted or duration of rest between sets, please log each set in a separate column (e.g. as Exercise 2, Exercise 3, etc.). In each row, there is a space to record up to 10 different exercises. However, if you perform more than 10 different exercises within one training session and you need additional space, please use the second row, starting from exercise 1, which will be the 11th exercise for you, etc.

<table>
<thead>
<tr>
<th>Exercise 1</th>
<th>Exercise 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the exercise</td>
<td>Name of the exercise</td>
</tr>
<tr>
<td>Number of sets</td>
<td>Number of sets</td>
</tr>
<tr>
<td>Number of repetitions</td>
<td>Number of repetitions</td>
</tr>
<tr>
<td>Weights lifted (kg)</td>
<td>Weights lifted (kg)</td>
</tr>
<tr>
<td>Rest between sets (s)</td>
<td>Rest between sets (s)</td>
</tr>
</tbody>
</table>

1) **RPE of training session or competition event.** The Borg Rating of Perceived Exertion Scale allows you to self-estimate the expended effort of your training. Notice that there are different RPE scales in use. For the purpose of our study, we will use Borg’s 0-10 RPE scale, where 0 means Rest and 10 means Maximal. Please assess your RPE 30 minutes after the end of your training session or competition event. You can find the RPE scale in the first page of your PA Log, called: Borg’s RPE Scale. The scale was also enclosed as an independent attachment in the e-mail that you received. Lastly, if you meet with a researcher at the University of Limerick, you should also receive the Borg’s scale during your appointment.

![RPE Scale](image)

1) **Goals of training session or competition event.** Please choose up to three goals of your training from the drop-down menu. If your goal is not listed, please use the ‘Other’ option and specify it. You can choose up to three goals. Please rate your goals from 1—the most important, 2—very important, and 3—important.
m) The next question refers to the **periods of high intensity within your training session or competition event**. Please choose ‘Yes’ or ‘No’ from the dropdown menu. If you choose ‘No’ that’s it what we ask you for. If your answer is ‘Yes’, please refer to the last two questions.

n) **Profile of exercises during a high-intensity phase within your training.**
   Please complete fields choosing high-intensity exercises, which you did during your session. Please complete fields regarding name of the exercises, number of sets and repetitions, weights lifted (kg), duration of rest between sets. If you repeat the same exercise in multiple sets but with different number of repetitions, weights lifted or duration of rest between sets, please log each set in a separate column (e.g. as Exercise 2, Exercise 3, etc.). In each row, there is a space to record up to 10 different exercises. However, if you perform more than 10 different exercises within one training session and you need additional space, please use the second row, starting from exercise 1, which will be the 11th exercise for you, etc.

o) **The overall duration of high-intensity exercises within a training session or competition event (min).** If your answer was Yes for the previous question please state the overall duration of high-intensity phase in minutes only. Use decimal values where applicable.
FAQ

Q1. What if I don’t have an Internet connection?
A: If you do not have an Internet connection all the time, you can download the Physical Activity Log, complete it and then update the information online later, until the end of the day.

Q2. I had one training session during a day. Should I complete one table regarding the type of the training and then should I leave the rest of tables blank?
A: Yes. Please choose an appropriate table regarding the type of training: either the one where you can record your: 1) endurance, skill, power and a team training session; or 2) resistance, rehabilitation and a mobility training session. If you have only one endurance training session per day, please complete only one table and leave the other table blank. If you have two training sessions per day, e.g. one endurance session and one resistance session, please complete two different tables. The one table will correspond with the endurance session and the other with the resistance type of training.

Q3. What should I fill in if it is my Rest Day?
A: If it is your Rest Day please record the date, day (Monday-Sunday) and choose the type of exercise in the first table. In this situation, the type of day will be Rest Day. That is all that we ask of you for that day.

Q4. What is it the RPE scale?
A: The RPE is a Borg Rating of Perceived Exertion Scale. It allows you to self-estimate the expended effort of your training. Notice that there are different RPE scales in use. For the purpose of our study, we will use Borg’s 0–10 RPE scale, where 0 means Rest and 10 means Maximal. Please assess your RPE 30 minutes after the end of your training session.
Q5. Where can I found the RPE scale?
A: You can find the RPE scale in the first sheet of your PA Log, called: Borg RPE Scale. In addition, the scale was enclosed in the e-mail that you received with these guidelines for the PA Log. You should also receive the hard copy during your meeting with a dietitian at the University of Limerick.

If you have any queries and questions please do not hesitate to contact Marta Kozior (PhD Researcher in Sport & Exercise Nutrition) by email: (deleted from this Appendix) or by telephone: (deleted from this Appendix).

Thank you for participating in our study!
Standard Operating Procedure for Nutritics Ltd. (Ireland) Data Coding

How to create a new subject profile and logs for data entry

1) Choose Start option on the left-hand side of the website and then New client.
2) In the field for name, provide Participant ID, which is a DXA code. If a DXA code is not assigned to a subject, please assign the next available code from the Database File created for Nutritics data entry. You received the Nutritics Database File together with this Standard Operating Procedure (SOP). It is also available to you online.
3) Fill in Lifestyle Adjustments fields, based on data collected in the Food, Fluid and Dietary Supplement Record and the Physical Activity Log.
5) Do not modify the EEA adjustments (in kcal) field.
6) Choose the appropriate group to which your subject belongs. If the group of interest is not listed, please contact Marta Kozior to set it up.
7) In the sharing section, add the ULResearch account as your collaborator. After data entry is completed, allow editing your information through the ULResearch account.
8) Write down your name in the notes for the subject level section (not log level section) so it is known who entered the data.
9) Now you can create a log.
10) Create a log on the right side of the screen.
11) Change untitled field into the number of a day, the date of record, the type of day, the phase of season. Please notice that Monday is always the first day of record and Sunday is the last (seventh) day of record. Please follow the format when entering a weighed food, fluid and dietary supplement record: Day 1, 22-11-2016, The type of day: 1, The phase of season: 6
12) If you are entering something other than a weighed food, fluid and dietary supplement record, use the following:
   - 24 hour recall: Day 1, 22-11-2016, The type of day: 1, The phase of season: 6, 24h recall
- Estimated food, fluid and dietary supplement record: Day 1, 22-11-2016, The type of day: 1, The phase of season: 6, EFFSR

- Diet history: Day 1, 22-11-2016, The type of day: 1, The phase of season: 6, DH

- Image-based food, fluid and dietary supplement record: Day 1, 22-11-2016, The type of day: 1, The phase of season: 6, IBFFSR

13) When entering retrospective data (e.g. 24 hour recall), the date entered should correspond to the date on which the food was consumed, not the date of data collection.

14) To enter data, use the Meal Log type, not the Day Log type.

15) One log will allow you to enter data from one day. To enter data from the rest of the six days, you will need to create a new log for each day.

16) Choose the number of eating occasions that you intend to enter for each day. You can add or delete the number of eating occasions during data entry if necessary. Add all recorded eating occasions in order from the earliest to the latest.

17) Modify custom fields for each eating occasion. Click on the heading of an eating occasion column, e.g. Meal 1 and provide information for the following: Date, Time (24-hour clock), The type of day, The location of eating occasion preparation, The phase of season and The type of meal. Instructions on how to classify eating occasions can be found at the end of this SOP. In the Nutritics Ltd. (Ireland) software, in the Eating Occasion column heading, the number of eating occasions are listed as meal 1, meal 2 etc. (the software properties).

Additional Information

18) Do not change the date of data entry. It is on the right side of the meal log.

19) Enter all fluids such as milk and chocolate milk, oils, and juices in ml if stated in millilitres. It will be automatically converted to grams. Please check product-specific gravity (density) for beverages other than water, tea, coffee, oils, milk, e.g. juices.

20) Enter the cooked weight of ingredients. If the raw weight is provided instead of cooked, please refer to The Composition of Food McCance and Widdowson’s, 7th Summary Edition to calculate the final weight of the cooked ingredients based on the % of weight change factor.
21) When creating a recipe, choose the Start option on the left-hand side of the Website, then New Recipe. Choose the appropriate weight change factor, which refers to the cooking method. You can choose the factor either for each ingredient or recipe.

22) When you create a New Food, choose the Start option on the left-hand side of the Website, then New Food. Provide the product name and the brand name provided on the company’s website. Provide the following information:
   – Food category,
   – Energy in kcal and kJ,
   – Macronutrients values,
   – Vitamins and other micronutrients values (if they are provided on the website), and
   – Allergens (always provided on the website).

23) Use the 24-hour clock when you are asked to provide time of an eating occasion or an exercise session.

24) In the log notes, please provide the additional information about type of exercise and time of exercise. It will help you to classify the types of eating occasion in the next stage.
   Classify the type of exercise (refer to pages 6–8) during training and competition days, include rest days as follows:
   1. Resistance
   2. Endurance
   3. Team
   4. Skill-based
   5. Power
   6. Rest Day
   7. Resistance & Endurance
   8. Mobility
   9. Rehabilitation

25) When you complete data entry, ensure you fill in the Nutritics© Database File (See point 2).

26) In Log Notes, enter the information related to training, rest and competition days as follows:
For training days, enter number, type and time of training sessions:

Training 1: Resistance
Time 1: 12:00-13:00

If more than one training, then:

Training 2: Endurance
Time 2: 17:15-18:00
Training 3: Rehabilitation
Time 3: 19:30-20:00

For rest days:

Rest Day

For competition days, enter number, type and time of competition events:

Competition 1: Team
Time 1: 14:00-15:30

If the exercise information was not provided, enter No exercise information provided into the Log Notes.

How to classify eating occasions

1. Check the time of eating occasions.

2. Choose main eating occasions in accordance with the time stamps for each. If more than one eating occasion is recorded within a particular time stamp, then only the eating occasion that provides the highest amount of energy is the main one. The rest of the eating occasions can be classified as snack, pre-sleep snack, fluid, alcoholic and beverages.

3. Eating occasions which are recorded less than 30 minutes of each other should be classified as one eating occasion, e.g. eating occasions consumed at 2:15 pm and 2:40 pm will be coded as one eating occasion consumed at 2:15 pm.

4. Alcoholic beverages will be chosen when the eating occasion provides only alcohol, e.g. dinner with a glass of wine will be classified as a dinner, but a glass of wine alone will be classified as an alcoholic beverage.
Table 1 Important information to custom fields’ data entry

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single eating occasion (EO)</td>
<td>An intake of energy-containing (&gt;0 kcal) food, fluids, including alcoholic beverages, and dietary supplements within a discrete, 30-minute timeframe. 0 kcal fluids, 0 kcal dietary supplements are classified as part of an EO if they are consumed at the same time as energy-containing foods, and/or fluids.</td>
</tr>
<tr>
<td>Type of EO</td>
<td>Numbers respond to EO types: 1–Snack, 2–Breakfast, 6–Lunch, 13–Dinner, 14–Pre-sleep snack, 15–Fluid, 16–Alcoholic beverage, 17–Dietary supplement.</td>
</tr>
<tr>
<td>Main EO</td>
<td>An EO with the highest energy intake consumed 6:00–11:00 is classified as breakfast, 11:01–15:00 lunch, 15:01–22:00 dinner (excluding alcohol consumed exclusively). Alcohol is classified as part of this category when it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.</td>
</tr>
<tr>
<td>Snack</td>
<td>Each EO consumed between the main EO; intake of energy-containing (&gt;0 kcal) food, beverages and dietary supplements. Alcohol is classified as part of this category if it is consumed at the same time as energy-containing food, fluids and/or dietary supplements.</td>
</tr>
<tr>
<td>Pre-sleep snack</td>
<td>A snack consumed 0–1 hour before bedtime.</td>
</tr>
<tr>
<td>Alcoholic beverage</td>
<td>A single EO that contains alcohol only. An alcoholic beverage consumed with other fluids (0 kcal) is classified under this category. Alcohol consumed with energy-containing food, fluids and/or dietary supplements is part of other EO categories that include main EO or snacks.</td>
</tr>
<tr>
<td>0 kcal fluid¹</td>
<td>Water or energy-free fluids consumed in isolation (not with an energy-containing item) that do not provide energy (0 kcal). Fluid intake with other energy-containing food, fluids and/or dietary supplements is part of other EO categories, such as main EO, snack or alcoholic beverage.</td>
</tr>
<tr>
<td>0 kcal dietary supplement¹</td>
<td>A dietary supplement is defined as ‘a food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit’ (Maughan et al. 2018). Only dietary supplements (0 kcal) consumed alone or with 0 kcal fluids should be included in this category. If a consumed supplement contains &gt;0 kcal or is consumed alongside energy-containing food and/or fluids, it should be classified as under one of the EO categories. Examples of products that are classified as EO and not supplements due to their contribution to energy include fish oils, spirulina powder, lecithin powder, acai powder, protein powder etc.</td>
</tr>
<tr>
<td>Location of EO preparation</td>
<td>Numbers 1–5 correspond to the location of EO preparation: 1–Home, 2–School, work, 3–Friend's or family’s house, 4–Pub, restaurant, hotel, shop, café, catering, 5–Take away, fast food outlet.</td>
</tr>
</tbody>
</table>
Type of day

Numbers 1–3 correspond to type of day: 1–Training day, 2–Rest day, 3–Competition day.

Phase of season

Numbers 1–6 correspond to the phase of season: 1–Pre-season, 2–In-season, 3–Off-season, 4–Injured, 5–Rehabilitation, 6–Not Applicable (for not competing, trained individuals).

Note: ‘0 kcal fluids and 0 kcal dietary supplements are coded into software under stand-alone descriptors but are not defined as EO. According to the definition, they do not contribute to the total energy intake. 0 kcal fluids and 0 kcal dietary supplements do not contribute to the analysis of EO frequency.

Training session classification

a) Resistance

i) Callisthenics - own body weight (e.g., bench press, squat, core training) (Brown, 2006)

ii) Weightlifting (e.g., barbells, weight machines), resistance band training (Brown, 2006)

iii) Static or dynamic exercises (e.g., repeated movements broken down into sets) (Dick, 2002)

A type of physical training practiced to develop muscle strength by the presence of resistance to a muscle's contraction. Exercises can be static (muscle contracting isometrically) or can be dynamic, involving movement. Resistance training exercises are made up of repetitions of movements broken down into sets (e.g. 4 sets of 12 repetitions of the press-up) (Tomlinson, 2010). Core training can involve resistance or can be callisthenic, its main function is to strengthen the core stabilizing muscles (Willardson, 2007). An example of a resistance training programme: training load: 3-4 times per week at 75-85% 1RM, 4-8 reps of 3-4 sets with 2-3 min resting periods (Brown, 2006).

b) Endurance

i) Swimming, running, cycling (Reaburn et al., 2011) HITT training. (Smith et al., 2013)

ii) Circuit training (cardiovascular endurance) (Brown, 2006)

iii) Track and field, soccer, football, boxing, rugby (Reaburn et al., 2011)

Endurance training uses large muscle groups in the execution of high-repetition, low-resistance exercises (e.g. running or cycling) to cause increases in maximal oxygen consumption (Pollock, 1973). HITT is used as an alternative to endurance training (Smith et al., 2013). Endurance activities and exercises are prolonged, typically for 30 minutes or more for beginner and 60-120 minutes for mature (Dick, 2002).
example of an endurance training programme: training loads: 5-7 times per week at <60% 1RM, 12-15 reps of 5-7 sets with <30 second rest periods (Brown, 2006).

3. Team
- Team sports disciplines e.g., GAA, soccer, basketball, rugby, field hockey (Werner et al., 1998)
- Includes resistance, endurance, power and speed and agility training (Gamble, 2009)
- Running, shuttles, circuits, strength, drills, training match (Gamble, 2009)
Team training sessions are made up of the main fitness components of endurance, speed (Power training), flexibility and strength (resistance training) (http://www.ulstergaa.ie/wp-content/uploads/coaching/articles/conditioning-the-GAA-Player.pdf, 2018). Examples of team sports include GAA, soccer, rugby, field hockey etc., (Werner et al., 1998).
Training includes strength training, explosive power training, speed and agility, endurance training and speed-endurance training (Gamble, 2009).

4. Skill-Based
- Motor skill, open skill, closed skill (Ericsson, 2010)
- Target practice, scoring practice, catching practice (Farrow et al., 2008)
- Drills, hand-passing, kick-passing, tackling drills (Farrow et al., 2008)
Skill-based training is made up of motor, open and closed skills that are specific to the sport. Closed skills are performed in an invariant environment and produce a specific motor pattern (ballet, gymnastics, figure skating, diving and synchronised swimming). Open skills are performed in a dynamic and variant environment, often including opponents (basketball, hockey, GAA, soccer, field hockey) (Ericsson, 2010).

5. Power
- Sprints, shuttle runs (Gamble, 2009)
- Low resistance, high-velocity exercises, squats, hang cleans, snatches (Brown, 2006)
- Plyometric (e.g., drop jumps, skipping, jump squats, step-ups) (Brown, 2006)
Power can be determined for a single body movement, a series of movements or a large number of repetitive movements (aerobic exercise). Power training is performed
with low resistance and high velocity, plyometric, ballistic and dynamic exercises. Examples: Drop jumps, MB power drop, box jumps, jump squats, sprinting. (Komi, 2003). An example of a training programme: training load: 1–2 times per week, 1–4 reps of 1–2 sets with 4–6 min rest periods (Brown, 2006).

6. Rest Day
   – No exercise

7. Resistance and Endurance
   – CrossFit, strength-endurance training (Hak et al., 2013)
   – Circuit training for muscular endurance (e.g., 12-15 reps of strength exercises and 5 minute cycle ergometer (Brown, 2006)

Recovery periods within resistance and endurance training are very strict e.g. 2 x 5 x 80 m runs with 30 s recovery. Strength endurance training is a resisted performance in a certain exercise or activity in the climate of endurance factors, i.e. 6 x 50 m swimming and towing a drag (Dick, 2002). Muscular endurance training sessions are of light loads (50–60% 1RM) with high volume (three to five sets of 15–20 reps) (Brown, 2006).

8. Mobility
   – Foam roll (e.g. spine, quad) (Dick, 2002)
   – Hip sequence, dumbbell squat press, lunges (Dick, 2002)

Mobility is the ability to perform joint actions through a wide range of movement (Dick, 2002). Mobility training includes active and slow, sustained exercises for each joint action and passive exercises with a partner, apparatus or bodyweight, kinetic exercise, combined elastic strength or mobility exercises including specific exercises related to sport-specific techniques (Dick, 2002).

9. Rehabilitation
   – Foam roller exercises, flexibility and stretching (Donatelli, 2007)
   – Physiotherapy, core stability/ rehabilitation (Norris, 1999; Donatelli, 2007)
   – Plyometric, Pilates, proprioception (Donatelli, 2007)

Sports rehabilitation is rehabilitation of the athlete back to optimum functional levels and optimum sports-specific fitness (www.society-of-sports-therapists.org, 2018). Recovery sessions include physiotherapy, aquatic therapy, Pilates, and plyometric
(Donatelli, 2007). Core stability would differentiate from calisthenics since, core stability would include exercises such as lumbar-pelvic rhythm, four-point kneeling, pelvic tilt using Swiss ball, abdominal hollowing, trunk curl, etc. (Norris, 1999; Donatelli, 2007).
TITLE: An investigation of dietary patterns and macronutrient intakes among resistance-trained men

AUTHORS: Marta Kozior1,2, Philip M. Jakeman1,2,3, Robert W. Davies1,2, Catherine Norton1,2,3.
1 Department of Physical Education and Sport Sciences, University of Limerick, V94 T9PX Limerick, Ireland
2 Food for Health Ireland (FHI)
3 Health Research Institute, University of Limerick, V94 T9PX Limerick, Ireland

PURPOSE: This study aimed to assess the adequacy of dietary patterns and macronutrient intakes in support of the adaptations to resistance training within a weekly microcycle of resistance-trained (RT) men using traditional dietary assessment methods.

METHODS: Thirty-seven RT men [age (y) Mdn (IQR) 24.9 (20.7–29.7), body mass (kg) M (SD) 81.3 (11.8)] were recruited to participate in this study. Dietary data were collected by self-reported 7-day weighed intake record and analysed on both a daily and per eating occasion (EO) basis using nutrition software. Adequacy was assessed against recommendations for this population (ACSM, 2016; IOC, 2018). Data are reported as M (SD), Mdn (25–75 percentile) and p-value (P).

RESULTS: Average daily energy intake for training day (TD) and rest day (RD) was 36 (7) and 34 (8) kcal·kg⁻¹·d⁻¹, respectively. Daily protein (PRO) intake (g·kg⁻¹·d⁻¹) was significantly greater than recommended minimum (1.6 g·kg⁻¹·d⁻¹) on TD [2.1 (0.5), P < .001] but was not different on RD [1.8 (0.6), P = .058]. Carbohydrate (CHO) intake (g·kg⁻¹·d⁻¹) was significantly lower than 5 g·kg⁻¹·d⁻¹ on both TD [3.5 (1.1), P < .001], and RD [3.3 (1.0), P < .001]. Daily frequency of EO was significantly higher than the recommended 3–4 EO (p < .001) for TD [5 (5–6)] and RD [5 (4–5)]. When analysed per EO (g·kg⁻¹·EO⁻¹), average PRO intake was significantly greater per main meal (MM) on TD [0.5 (0.4–0.6), P < .001] and RD [0.5 (0.4–0.6), P < .001], but not significantly different per snack (SN) [0.2 (0.1–0.3)] for TD (P = .254) and RD (P = .111) vs recommended 0.25 g·kg⁻¹·EO⁻¹. CHO intake (g·kg⁻¹·EO⁻¹) per MM was 0.9 (0.7–1.1) for TD and 1.0 (0.7–1.1) for RD. CHO (g·kg⁻¹·EO⁻¹) consumed per SN was 0.4 (0.3–0.5) for both TD and RD. Daily number of MM was 3 (3, 3) for TD and RD, and of SN were 3 (2–4) for TD, 2 (1–3) for RD.

CONCLUSION: RT men met dietary recommendations to optimise adaptation to resistance training. However, the traditional dietary assessment methods do not address the importance of quantity, quality (source), timing, distribution and frequency of nutrients relative to a specific training session, termed peri-training nutrition (PTN), to optimise training adaptation. Future work must work towards analysis methods in support of periodised, personalised nutrition, relative to a specific training stimulus. FHI Grant TC20130001.
TITLE: Assessing adequacy of protein feeding in resistance-trained athletes; re-visited through peri-training nutrition (PTN)

AUTHORS: Marta Kozior1,2, Philip M. Jakeman1,2,3, Robert W. Davies1,2, Catherine Norton1,2,3.

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2 Food for Health Ireland (FHI)
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Key opinion leaders in sport and exercise nutrition emphasise the importance of a personalised and periodised approach for athletic populations. The PTN paradigm proposed here places aims and characteristics of training and competition at the core of a dietary assessment, providing potential to apply this recommended approach, and identifying therefore–unexploited opportunities for nutrient optimisation to support training adaptations. PTN acknowledges the importance of the nutrient intakes (type, quality (source), quantity, timing, distribution and frequency) to support individual training sessions and competitive demands.

Our objective was to determine 1) the adequacy of reported protein (PRO) intake and 2) frequency and distribution of eating occasions (EO) relative to the demands of a resistance training (RT).

Data are presented for RT athletes as Mdn (IQR) [N = 32, aged (y) 25.1 (9.5), body mass (kg) 81.4 (14.3), a RT history ≥6 months and completing 3 (3) RT sessions weekly]. Dietary data was collected by self-reported 7-day weighed intake record, and analysed using Nutritics© V5.09. The adequacy of PRO intake was assessed against recommended daily (1.6–2.2 g·kg⁻¹·d⁻¹) and per EO (≥0.25 g·kg⁻¹) intakes for this population. Investigation of EO frequency and distribution against recommendations (3–4 EO·d⁻¹ and distribution of every 3–5 h) was also completed. PRO feeding in support of the adaptive outcome of RT was assessed in the 24h recovery phase.

The reference quantity for daily PRO intake was met for 18%, exceeded (>2.2 g·kg⁻¹·24h⁻¹) for 52% of all 24h post-RT phases [N = 61, 2.2 (1.2) g·kg⁻¹·24h⁻¹]. Adequacy in PRO consumption per EO (≥ 0.25 g·kg⁻¹·EO⁻¹) was achieved for 63% of all EO 0.3 (0.4) g·kg⁻¹]. The number of EO within a 24h post-RT phase was 5 (2). 98% of RT sessions were supported with at least 3 EO. EO were consumed every 2 h 20 min (1 h 59 min), but 29% of them were distributed every 3-5 h.

This data highlights the need for advancements in dietary assessment in athletic populations towards periodised, personalised nutrition, with training at the core of this process. PTN assessment allows for effective monitoring of habitual nutritional practices of athletes. This approach to dietary assessment in athletic populations could provide opportunities to further support training adaptations and confer competitive advantage.
Appendix 6 Dietary standardisation information for participants

Additional information about your diet 72 hours before and after the first biopsy

72 hours before the first biopsy

1. Please do not consume any supplements (whey protein, multivitamins, fish oil, magnesium, vitamin D, etc.) 72 hours before the study.
2. Furthermore, 72 hours before the study please refrain from consuming tea, coffee and alcohol. Decaffeinated coffee and black tea as well as still and sparkling water is allowed to drink.

After the first biopsy

1. Every day, during 6 days, 5 meals will be provided to you every morning. You are asked to consume all eating occasions provided for each day.
2. During the 6-days controlled diet study you are asked to consume provided meals and snacks according to the time provided on food packages. Please check if you picked all boxes for each meal and snack.
3. You are asked to consume each meal and snack within 30 minutes.
4. Meals and snacks can be packed in more than one food container, including bottles. Meals can include fruits, juices, smoothies, and shakes.
5. Please do not consume any additional food to what you receive.
6. Please do not consume any supplements (whey protein, multivitamins, fish oil, magnesium, etc.) during the study.
7. Please refrain from tea, coffee and alcohol. Decaffeinated coffee and tea without sugar and milk as well as still and sparkling water is allowed ad libitum during the study.
8. Please refrain from juices, smoothies, shakes, unsweetened and sweetened beverages other than provided in your meal plan.
9. Please record the daily volume of water you drink, decaffeinated coffee and decaffeinated black tea on the provided daily checklist.
10. Please assure that you return daily checklist with all food containers and any leftovers in the following day but before you take meals and snacks for the next day.
11. If you are not sure which meal you should consume next, please check labels on food containers. The label will include your ID, body mass, number of the day (e.g. Day 1, Day 2), eating occasion type and name (e.g. Day 5, Breakfast, Omelette with mushrooms, tomato and spinach, white bread, and orange juice) and time of meal consumption (specified for each participant). In addition you can find meals and snacks descriptions (e.g. Day 2, Dinner, Beef Bourguignon, Apple, Pear) in your the daily checklist.
12. All food should be stored in a fridge at temperature between 1–5°C.
13. You can reheat all meals and snacks, according to your preferences, e.g. in a microwave for 1–3 minutes.
14. If you have any questions or reflection about your diet and any other related information, please contact Marta Kozior (email deleted from this Appendix).
Appendix 7 List of additional snacks

List of Additional Snacks

We understand that 3-hour gap between meals can be challenging, especially if you are used to snacking between meals or if the gap between your habitual meals is shorter than 3 hours. If you are really hungry between meals and snacks and you think that you cannot resist until the next meal, please choose the snack from options listed below. The list of additional snacks was created to give you an opportunity to consume standardised energy and macronutrients matched snacks. These listed below snacks are not provided. It means that you can purchase them yourself. However, we ask you not to consume different food than are listed below as it may affect your participation in the research.

Please assure that all ingredients are weighed and you write down any additional snacks consumed in your daily checklist.

Option 1
150g of red grapes

Option 2
60g of fresh blueberries
50g of dried cranberries

Option 3
270ml of apple juice

Option 4
20g of dried mango
25g of dried cranberries

Option 5
115g of raw pineapple
20g of raisins
Appendix 8 Daily dietary checklist

A checklist for each day looked the same, except a meal plan that changed every day.

**Day 1 – Checklist**

(Please tick appropriate boxes and fill empty fields)

**Today:**
- ☐ I received food and beverages for 5 different eating occasions for the Day 1.
- ☐ I did not consume any alcoholic beverages.
- ☐ I did not consume any additional supplements (e.g. whey protein, multivitamins, fish oils, etc.).
- ☐ I did not consume any additional meals or snacks.
- ☐ I did not drink any caffeinated tea, caffeinated coffee and another (not provided) beverages. The exceptions are water, decaffeinated coffee and decaffeinated tea, which I can drink *ad libitum*.
- ☐ I drank still and/or sparkling water and/or decaffeinated coffee and decaffeinated tea.
- ☐ I ate all provided meals and snacks.
- ☐ I returned empty food containers from the Day 1.

If you did not tick some of boxes above, please give a reason why not, for each box you did not tick.

If you have any leftovers after the day 1, please return them in the original packages.

If you have any leftovers after the Day 1, please return them in the original packages.

If you consumed another food in addition to provided diet please record it in the table on the next page. In the same table, please record all beverages (also water) which you drank and which were not provided.
Meal Plan for Day 1.

<table>
<thead>
<tr>
<th>Time, Meal Type and Place</th>
<th>Food or Drink Description and Brand Name</th>
<th>Quantity</th>
<th>Quantity left over</th>
<th>Cooking Method</th>
<th>Any Comment/ Additions at cooking/eating (dressings, condiments, herbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast</td>
<td>Porridge made with rice milk, coconut oil and banana topped with cranberries and honey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunch</td>
<td>Poached eggs with asparagus and sweet potato chips, orange juice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snack</td>
<td>Ham sandwich with tomato and lettuce, fat-free fruit yoghurt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dinner</td>
<td>Grilled chicken breast in gravy with boiled sweetcorn, peas, baby carrots and mashed potatoes, strawberry and banana smoothie</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-sleep Snack</td>
<td>Greek yogurt with cashews and fresh berries topped with honey</td>
<td></td>
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</tr>
</tbody>
</table>
Appendix 9 Modification of dietary intake record and guidelines

Note: Appendix 9 includes the dietary records and guidelines modified after implementing a 7-day physical activity log.

1. Amended Section of the Food, Fluid and Dietary Supplement Diary

<table>
<thead>
<tr>
<th>Participant I.D.</th>
<th>Was all water intake recorded for today?</th>
<th>Yes</th>
<th>No</th>
<th>If no, how much water was consumed today?</th>
<th>RECording Date</th>
<th>RECORDING DAY (circle one)</th>
<th>MTWTFSS</th>
<th>1 2 3 4 5 6 7</th>
</tr>
</thead>
</table>

Please use this space to detail any composite dishes, homemade recipes and ingredients used, that you may have consumed throughout the day, e.g., Lasagne, Stew, Homemade Bread. This sheet can be also used to attach food packaging/wrappers here which are difficult to describe e.g., frozen vegetables mix, products enriched in vitamins.

Please use this space to detail any medication, vitamin, mineral or herbal supplements that you have taken throughout the day. If listing medications or supplements please include product name, manufacturer, dose, time of intake and during which meal or between which meals have been taken.

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Dose</th>
<th>Time</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Did you fill out your Physical Activity log for today?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

Please use the space provided below to leave any comments relating to the Physical Activity log.

```
2. Amended Section of the Food, Fluid and Dietary Supplement Diary Guidelines

Additional space on the next sheet

Please use this space to detail:

1. Amount of water intake each day if you did not record all water intake during the day. Provide the amount of water drunk, which has not been recorded earlier during a day.

<table>
<thead>
<tr>
<th>Was all water intake recorded for today?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>If yes, how much water was consumed in addition to that you have recorded today?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Any composite dishes, homemade recipes and ingredients used that you might have consumed throughout the day, e.g. lasagne, stew, homemade bread. This sheet can also be used to attach food packaging or wrappers, which are difficult to describe, e.g. frozen vegetable mix, products fortified in vitamins or minerals.

3. Any medication, vitamin, mineral or herbal supplements that you have taken throughout the day. If listing medications or dietary supplements, please include product name, manufacturer, dose, time of intake and food consumed or fluids drunk during their intakes.

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Dose</th>
<th>Time</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin C (Jarrow)</td>
<td>VIT</td>
<td>1 capsule 500 mg</td>
<td>08:00</td>
<td>Drank 200 ml orange juice with it</td>
</tr>
</tbody>
</table>

4. Any exercise that you have done throughout the day, including assessment of the RPE 30 min post-training session, and have not recorded in your Physical Activity Log (PA Log) yet. Please record all the training-related information in the PA Log as soon as possible.

<table>
<thead>
<tr>
<th>Did you fill your Physical Activity Log for today?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please use the space provided below to leave any comments relating to the Physical Activity Log</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>