Performance Nutrition

CASE STUDY

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Fuelling gold medals: developing a 'periodised nutrition system' for elite athletes and applying it in practice

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Abstract

The concept of periodised nutrition is well-established within performance nutrition support to appropriately fuel elite athletes while maximising the adaptative response from training. Despite this, there may still be little planning and integration of training prescription and nutrition between the performance nutritionist and multi-disciplinary team. Consequently, the aim of this case study was to (1) propose a 'Periodised Nutrition System' which can be utilised by performance nutrition practitioners when working with athletes, through amalgamating previously published literature, tools, and approaches in the literature; (2) discuss how this can be administered in practice, collaborating with the coach, multidisciplinary team and athlete; (3) present a case study of the proposed 'Periodised Nutrition System' and its utilisation with a world class swimmer leading into the 2024 Paris Summer Olympic Games. The 'Periodised Nutrition System' presents different 'performance plates', quantities of different foods to fit into the 'performance plates' to aid recipe development, and how they may practically fit into an athlete's training periodisation alongside theoretical rationale. The case study demonstrates a 'real world' scenario of its utilisation with an elite swimmer, transitioning through three separate performance goals while reducing body mass by 1.9 kg, sum of eight skinfolds by 20.1 mm, predicted fat mass by 2.6 kg and an increase in predicted lean mass by 0.6 kg over a six-week mesocycle. The study highlights that the 'Periodised Nutrition System' enables the practitioner to develop a structure to their support, aligning nutritional strategies with the training periodisation of the athlete, allowing for an individualised approach, specific to the athlete's performance goal(s) and the desired adaptation of a training session.

Keywords Performance nutrition, Sports nutrition, Periodised nutrition, Swimming, Olympics

Introduction

The concept of training periodisation has been well established since the seminal work of Dr. Hans Selye in the early 1950s [1]. This has paved the way for a mixture of different training periodisation approaches such as classical, block, pyramidal, polarised, and threshold models [2–4], with these approaches being utilised in a variety of sports such as swimming [5], and track and field [6]. The main aim of training periodisation, regardless of the approach, is to cyclically order specific training exercises and sessions, while navigating an athlete through a short (microcycle; days and within days), medium (mesocycle; weeks) and long (macrocycle; months to year(s)) term planning process, with the aim of applying the principles of progressively overloading and recovering an athlete, specific to their event, with the intention of achieving peak performance in a sporting event [2, 3].

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Nutrition sits in tandem with an athlete's training programme, ensuring that an athlete has the appropriate amount of macro-and micro-nutrients to optimise their health, physical performance, training adaptations, and body composition [7], while the supplementation of some ergogenic aids may further augment training and competition performance [8]. The concept of 'periodised nutrition' has been developed as a greater understanding of the role(s) nutrition can play in an athletes training and performance [9, 10]. 'Periodised nutrition' has been defined as "the planned, purposeful, and strategic use of specific nutritional interventions to enhance the adaptations targeted by individual exercise sessions or periodic training plans, or to obtain other effects that will enhance performance longer term" [10]. A 'Framework for Periodisation of Nutrition' has since been developed [11], presenting how to implement nutritional strategies on a macro-, meso- and microcycle level. It also highlights how a variety of nutrients such as carbohydrate, protein, iron, and creatine can be periodised on a macro-, meso- and microcycle level [11].

Performance nutritionists work with athletes to ensure that their diets contain optimal amounts of macro- and micronutrients. Protein intake generally remains consistent across a macrocycle at a suggested intake of 1.3–1.8 $g \cdot kg \cdot bm^{-1}$ per day [12], although this may need to be increased to ~1.6–2.4 $g \cdot kg \cdot bm^{-1}$ if the athlete's goal is to reduce fat mass, while maintaining lean mass [13]. Fat intake is suggested to be constant at ~30% of total energy intake per day [14]. Consequently, the alteration of daily energy intake is suggested to come from a manipulation in carbohydrate [15]. Contemporary guidelines suggest carbohydrate intakes between 3–12 $g \cdot kg \cdot bm^{-1}$ per day depending on the daily fuelling and recovery needs of the individual [15]. It has been hypothesised that by manipulating carbohydrate intake, and as a result, muscle glycogen content on a session-by-session basis may augment aerobic adaptations [16]. While high glycogen availability is crucial during high intensity training sessions (e.g. zone 3; > 4 $mmol \cdot L^{-1}$) [17], commencing some low intensity sessions (e.g. zone 1; <2 $mmol \cdot L^{-1}$) with low glycogen availability, or fasted, has been shown to activate acute cell signalling kinases (e.g. AMPK, p38) [18–26], transcription factors (e.g. p53, PPAR) [26–28], and transcriptional coactivators (e.g. PGC-1α) [29], that may augment favourable endurance adaptations such as oxidative enzyme activity [30–33], mitochondrial biogenesis [27, 29], angiogenesis [34], and increased lipid oxidation [19, 22, 26, 27, 31, 32, 35, 36]. Consequently, the concept of the 'glycogen threshold hypothesis' has been developed over the past decade, whereby a 'threshold level' of glycogen is required to complete the required volume and intensity of a training session but may also modulate the activation of molecular machinery training responses [37]. This has led to the creation of an amalgamation of targeted carbohydrate availability approaches (e.g. low, moderate, and high) throughout a microcycle [10, 26, 37], whereby glycogen is 'cycled' to optimise physical performance and adaptations [37]. It should be noted that while training with low glycogen availability may augment the cell signalling responses which underpin aerobic adaptations, some studies have found that it does not translate to enhanced performance over a macro- or mesocycle, when compared to training with high glycogen availability [38]. Consequently, there should be enough carbohydrate to sustain the required training load to promote optimal adaptations [39], as an athlete's ability to accumulate training load may be the greatest driver of adaptations [40].

As well as macronutrients, specific micronutrients, phytonutrients, and supplements may also be periodised at specific times throughout a macro-, meso- or microcycle. For example, athletes' may have an increased iron requirements while training at altitude [41], foods high in quercetin may be promoted during periods of muscle damage [42], and creatine can be supplemented if an athlete's goal is to increase strength throughout a mesocycle [43] or achieve a greater replenishment of glycogen resynthesis from one high intensity session to the next during a microcycle [44].

With a growing appreciation that nutrition support could be provided on a microcycle basis, there has been a rise in the number of performance nutritionists [45]. Many national governing bodies of Olympic and Paralympic sports organisations, as well as professional sports teams now employ a performance nutritionist on a part time or full-time basis, tasked with preparing and delivering athletes' nutrition support [45]. Despite this rise, there is reported to be little planning and integration of training prescription and nutrition between the performance nutritionist and multi-disciplinary team [10]. Performance nutritionists may work in isolation, while it has been highlighted that a multidisciplinary approach can achieve outcomes which can't be achieved from a single discipline in the context of athlete injury rehabilitation [46]. Similarly, to achieve an optimal periodised nutrition approach, performance nutritionists should deliver nutrition support as part of an integrated multidisciplinary team, with all key stakeholders (coach, athlete, nutritionist, conditioning coach, medical, psychologist, etc.) all aligned on the physiological, neuromuscular, structural and psychological demands of the athletes' event, while understanding how the athlete can bridge any gaps to ensure success during competition [11]. Consequently, performance nutritionists should periodise nutrition strategies on a microcycle level, aligned to the coach's training periodisation, and athlete's performance goal(s). Stellingwerff et al., (2019) [11] proposed that there needs to be better quantification of knowledge and application of nutritional periodisation approaches among athletes. Previous research has proposed various tools to enable athletes to periodise their nutrition, such as periodisation approaches [11], colour coded frameworks [37, 39], and educational plate tools [47]. Stellingwerff et al., (2019) [11] reported numerous approaches which can be implemented to form a 'periodised nutrition' approach such as: 'train high'; 'consume a pre training meal of 1–3 $g \cdot kg \cdot bm^{-1}$ of carbohydrate'; 'carbohydrate is withheld in recovery or suboptimal intakes occur' [11]. Impey et al., (2017) [37] and Poldlagar & Wallis, (2022) [39] both proposed colour coded frameworks (red = low; amber = moderate; and green = high) to manipulate and periodise carbohydrate intake based on the upcoming demands of activity, with the aim of ensuring appropriate fuelling and optimising training adaptations. Reguant-Closa et al., (2019) [47] created and validated the 'Athlete's Plate Educational Tool' with the aim of the providing a visual aid for performance nutritionists to enable athletes to adjust their dietary intake based on their training load.

To the authors knowledge, no one has ever proposed a 'Periodised Nutrition System' which amalgamates all these proposed tools such as periodisation statements, a RAG rated colour coded system, and visual tools, to apply nutrition periodisation approaches, specific to an athlete's performance goal(s), and desired training adaptation. Therefore, the aim of the 'Periodised Nutrition System' is to further advance the quantification of knowledge and application of nutritional periodisation approaches among athletes, as proposed by Stellingwerff et al., (2019) [11].

To this extent, the aim of this case study is to (1) propose a 'Periodised Nutrition System' which can be utilised by performance nutritionists when working with athletes in a variety of sports; (2) discuss how this can be administered in practice, collaborating with the coach, multidisciplinary team, and athlete; (3) present a case study of the proposed 'Periodised Nutrition System' and its utilisation with a world class swimmer (as defined by McKay et al., 2022 [48]) in the build-up to the 2024 Paris Summer Olympic Games.

'Periodised Nutrition System'

Table 1 displays the characteristics of the 'Periodised Nutrition System', outlining the different 'plates', their energy and macronutrient composition, examples of each plate, how you may practically apply them in training sessions, and the theoretical rationale underpinning this. Supplementary files 1 and 2 display the 'Periodised Nutrition System' infographics and an example recipe card.

As previously discussed, performance nutritionists can typically work in isolation, and this may lead to little planning and integration of training prescription and nutrition between the nutritionist and multi-disciplinary team [10]. Consequently, Figure 1 outlines the process of how the 'Periodised Nutrition System' can be embedded alongside an athlete's training periodisation. The aim of this is to achieve a greater collaboration between the performance nutritionist, athlete and multi-disciplinary team.

From Theory to Practice: ''Periodised Nutrition System' Case Study with a World Class Level Swimmer

Athlete Profile

The swimmer was a world class level [48] female swimmer who was part of the Aquatics GB 2024 Paris Summer Olympic Swimming Team. The swimmer had previously utilised nutrition support with the performance nutritionist since September 2022, with this continuing through to the 2024 Paris Summer Olympic Games. Previous nutrition support (prior to switching to a 'Periodised Nutrition System' model) had been provided on an infrequent basis (roughly x1 nutrition consultation and x1 body composition assessment every 4–6 weeks). While nutrition support had been ongoing with the swimmer since September 2022, the swimmer and performance nutritionist collaborated on a periodised nutrition approach from June 2024 to ensure that they achieved their performance goals. This was initially driven by the performance nutritionist but as the swimmer gained experience and confidence in the approach, they were empowered to lead the process moving forwards.

The case study below outlines the process to establish the periodised nutrition support and presents a snapshot of the application of the 'Periodised Nutrition System' in action over six microcycles in the final mesocycle prior to the 2024 Paris Summer Olympic Games (mesocycle three = April 2024 to August 2024), between the dates of Monday 3rd June to Sunday 14th July. Previous self-reported food diaries had shown the swimmers energy balance (energy intake whereby body mass is maintained) to be roughly 2300–3000 kcal depending on the volume and intensity of training. This is consistent with previous research quantifying the energy balance of female swimmers [54]. Details of the methodology of how the swimmer completed previous food diaries are reported in section "Monitoring & Refinement". The swimmer and coach were informed about the purpose of the support provision, and the first author answered any questions they had. Written informed consent which adopted the ethical principles described by Sheffield Hallam

Table 1 The 'Periodised Nutrition System'

Name of 'Plate'	Colour Code	Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Food Quantity Examples**	Plate Description	Food & Drink Examples	Practical Implementation in Training sessions	Theoretical Rationale
The 'Repair' Plate	Green	320–580	0–50	35–50*	~25	CHO: Rice = ~25–50 g Pasta = ~25–50 g Bread = ~40–60 g Oats = ~30–55 g Potato = ~125–200 g PRO: Chicken breast = ~130–180 g Beef steak (sirloin) = ~130g-180 g Beef mince (extra lean) = ~140–190 g Salmon (fillet) = ~130–180 g Salmon (smoked) = ~130–180 g Cod = ~170–230 g Egg = ~220–240 g Tempeh = ~140–190 g FAT: Avocado = ~80 g Olive oil = ~13 g Mixed nuts = ~25–30 g Mixed seeds = ~25–30 g Nut butter = ~25 g	Predominantly protein and **low carbohydrate plant based (vegetables, nuts, seeds, some fruits)	Omelette; shakshuka; chicken kebabs with vegetable salad; Turkish egg pot; yogurt, mixed nuts and berries	Zone 1 (< 2 mmol·L^{-1}) training session; reduce non-functional mass; train low (glycogen session); recover low / sleep low strategy	**Zone one (< 2 mmol·L^{-1}) training session:** Zone 1 sessions may utilise fat as a fuel and therefore less carbohydrates are required [17]. This may also augment training adaptations (see below). **Reduce non-functional mass:** Lower kcal content of the 'Repair' plate is intended to create caloric deficit which can reduce non-functional mass (i.e. reduce fat mass of an individual) [49] **Train low (glycogen session):** Low muscle glycogen status, either by commencing exercise with reduced amounts or depleting throughout the duration of an exercise bout is associated with upregulated nuclear and mitochondrial genome activity through the activity of cell signalling proteins AMPK, PPAR, P38, PGC-1α [18–33, 35]. Chronically, this may increase whole body and intramuscular lipid metabolism which could increase exercise capacity and performance [19, 22, 26, 27, 31–33, 35, 36]

Table 1 (continued)

Name of 'Plate'	Colour Code	Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Food Quantity Examples**	Plate Description	Food & Drink Examples	Practical Implementation in Training sessions	Theoretical Rationale
The 'Fuel' Plate	Amber	520–780	50–100	35–50*	~25	CHO: Rice = ~75–100 g Pasta = ~75–100 g Bread = ~100–150 g Oats = ~85–110 g Potato = ~350–400 g PRO: Chicken breast = ~130–180 g Beef steak (sirloin) = ~130g-180 g Beef mince (extra lean) = ~140–190 g Salmon (fillet) = ~130–180 g Salmon (smoked) = ~130–180 g Cod = ~170–230 g Egg = ~220–240 g Tempeh = ~140–190 g FAT: Avocado = ~80 g Olive oil = ~13 g Mixed nuts = ~25–30 g Mixed seeds = ~25–30 g Nut butter = ~25 g	Mixed meal of protein, carbohydrate and **low carbohydrate plant based (vegetables, nuts, seeds, some fruits)	Animal (e.g. meat, fish etc.) or plant based protein (e.g. soya, tempeh etc.) source with carbohydrate source (e.g. rice, pasta, potato etc.) and vegetables (e.g. broccoli, carrots etc.)	Zone one (< 2 mmol·L^{-1}) training session; zone two training session (< 2–4 mmol·L^{-1}); zone three training session (> 4 mmol·L^{-1}); maintain current body composition	**Zone one (< 2 mmol·L^{-1}) training session:** Zone 1 sessions may utilise some carbohydrates as a fuel [17]. Depending on the performance goal(s) of the athlete, it may be appropriate to ensure energy balance and carbohydrate availability [50], even during zone one training sessions. **Zone two (2–4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone two training sessions and therefore the athlete needs to ensure carbohydrate availability to optimise their performance [17] **Zone three (> 4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone three training sessions and therefore the athlete needs to ensure carbohydrate availability to reach the required intensities [17] **Maintain current body composition:** The 'fuel' plate represents a moderate caloric amount which can be utilised to maintain an athlete's current body composition [49]

Table 1 (continued)

Name of 'Plate'	Colour Code	Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Food Quantity Examples**	Plate Description	Food & Drink Examples	Practical Implementation in Training sessions	Theoretical Rationale
The 'Perform' Plate	Red	720–980	100–150	35–50*	~25	CHO: Rice = ~140–180 g Pasta = ~140–170 g Bread = ~200–250 g Oats = ~150–200 g Potato = ~600–700 g PRO: Chicken breast = ~130–180 g Beef steak (sirloin) = ~130g-180 g Beef mince (extra lean) = ~140–190 g Salmon (fillet) = ~130–180 g Salmon (smoked) = ~130–180 g Cod = ~170–230 g Egg = ~220–240 g Tempeh = ~140–190 g FAT: Avocado = ~80 g Olive oil = ~13 g Mixed nuts = ~25–30 g Mixed seeds = ~25–30 g Nut butter = ~25 g	Meal high in carbohydrate with moderate protein and **low carbohydrate plant based (vegetables, nuts, seeds, some fruits)	Animal (e.g. meat, fish etc.) or plant based protein (e.g. soya, tempeh etc.) source with carbohydrate source (e.g. rice, pasta, potato etc.) and vegetables (e.g. brocoli, carrots etc.)	Zone two training session (< 2–4 mmol·L^{-1}); zone three training session (> 4 mmol·L^{-1}); increase lean mass	**Zone two (2–4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone two training sessions and therefore, the athlete needs to ensure carbohydrate availability to reach the required intensities [17] **Zone three (> 4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone three training sessions and therefore, the athlete needs to ensure carbohydrate availability to reach the required intensities [17] **Increase lean mass:** The 'perform' plate can increase caloric intake, promoting increases in lean mass when conducted alongside an appropriate conditioning programme [49]
'Sustain' Snacks	Yellow	80–370	20–60	0–10	0–10	N/A	High glycemic index carbohydrates which are lower in fibre content These are intended to be consumed either pre, during, or post exercise, or as a snack to increase glycogen content whereby this cannot be achieved through repair, fuel and perform plates	Energy ball; ripe banana; dried fruit; rice Krispies bar; sports drink; oat bar; children's cereal (e.g. coco pops); sweets; Weetabix with honey; jam on white bread; granola with milk or yogurt	Zone 2 training session (< 2–4 mmol·L^{-1}); zone 3 training session (> 4 mmol·L^{-1})	**Zone two (2–4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone two training sessions and therefore the athlete needs to ensure carbohydrate availability to reach the required intensities [17] **Zone three (> 4 mmol·L^{-1}) training session:** Carbohydrates are the predominant energy source during zone three training sessions and therefore the athlete needs to ensure carbohydrate availability to reach the required intensities [17]

Table 1 (continued)

Name of 'Plate'	Colour Code	Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Food Quantity Examples**	Plate Description	Food & Drink Examples	Practical Implementation in Training sessions	Theoretical Rationale
'Repair' Snacks	Blue	80–255	0–10	~20	0–15	N/A	Protein snacks These are intended to be consumed either post exercise as a recovery strategy, or as a snack to increase protein intake whereby this cannot be achieved through repair, fuel and perform plates (e.g. individual has high lean mass)	Protein bar, protein shake, Greek yogurt and berries, seasoned meat or tempeh skewers	Zone 1 (< 2 mmol·L^{-1}) training session; maintain lean mass while reducing non-functional mass; train low (glycogen session); recover low / sleep low strategy; increase lean mass	**Zone one (< 2 mmol·L^{-1}) training session:** Zone 1 sessions may utilise fat as a fuel and therefore less carbohydrates are required [17]. By keeping protein intake consistent, through 'repair snacks', this helps maintain lean mass [49] **Maintain lean mass while reducing non-functional mass:** Extra repair snacks can increase protein intake. This has been shown to maintain lean mass while reducing non-functional mass (1.6–2.4 g·kg·bm^{-1}) [13, 49]

*'Plates' consumed at breakfast would contain ~20 g protein rather than 30–50 g protein due to typical foods consumed at breakfast such as oats, dairy, eggs being lower in protein than typical lunchtime and evening meal foods such as meat, fish, tofu

** Low carbohydrate = <10g per 100g

***Weights of food are raw quantities

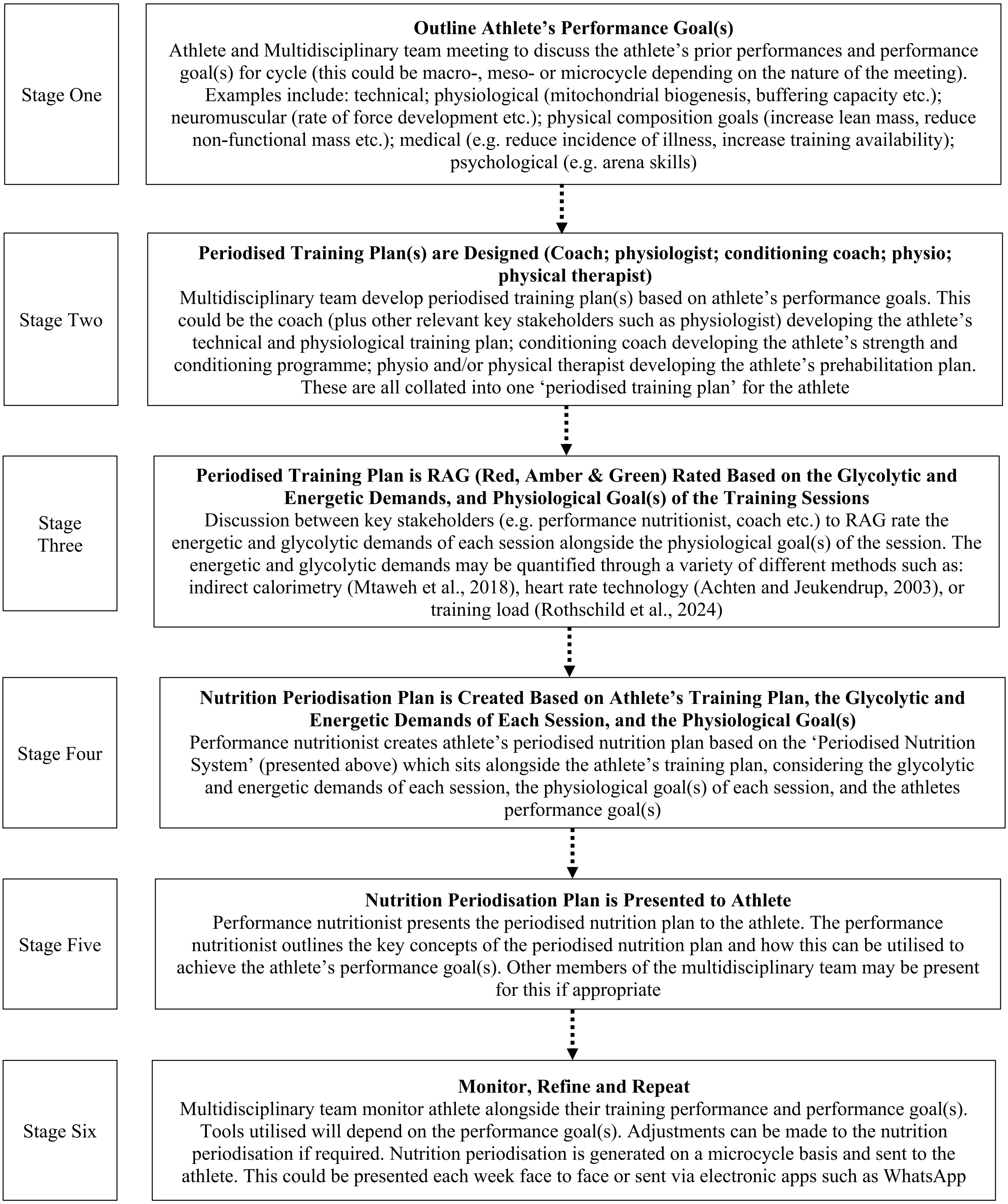

Fig 1 The six stages of embedding the 'Periodised Nutrition System' [51–53]

University Ethics Committee was provided by the athlete and coach, and consequently both provided consent for the publication of this case study.

Athlete Performance Goal(s)

In September 2023, at the beginning of the 2023/24 swimming season, in collaboration with the swimmer,

Table 2 Swimmers' performance goals

Goal	Goal Objective	What is Determined as Success?	Method	Measure and Monitoring
1	Increased skills around the wall	Push offs, underwater dolphin kick and breakouts improved. Speed in, around and through the breakout developed. Able to stay in the hunt in races and use clean swimming super strength	Technical analysis and regular feedback to the swimmer. Speed skill progressions bolted on to the end of sessions	Times fed back after major meets of each cycle. Physical and technical measures set by multidisciplinary team (e.g. power output by strength and conditioning coach)
2	Improve (50/100) speed and speed endurance (200) on fly and breast strokes	Technical improvements and deliver increased propulsion and reduced drag on fly and breast technique	Pool sets, kick sessions, utilisation of swim bench, land work adapted to support this goal	Technical and physical measures set by leads
3	Aquatic profile – Achieve best physical condition for the 2024 Paris Summer Olympic Games	Optimal strength profile (lifting and body control), flexibility profile, body composition, drag profile, technical stroke profile. Establish and then maintain throughout the season	Aligned multidisciplinary team approach – Practitioners define optimum in their areas and track throughout the season	Cross-team monitoring – Quantify drag profile through tow rig, power output using force decks, body composition via sum of 8 skinfolds, energy intake and nutritional habits via communication with the athlete and food diaries

coach, and multidisciplinary team, three performance goals were outlined for the swimmer. Table 2 displays the performance goals of the swimmer.

Each performance goal had a 'driver' who was responsible for collating the information and feeding back to key stakeholders. The performance nutritionist was assigned as the 'driver' for the goal 3; Aquatic profile – Achieve best physical condition for the 2024 Paris Summer Olympic Games. Aquatic profile is defined as an overarching concept which relates to how a swimmer presents in the water. This can be separated into a swimmer's technical profile in the water (cross sectional area, propulsion, drag, efficiency, buoyancy, breathing mechanics, and pattern) and physical profile out of the water (stature, mass, body composition, strength, posture, limb length, flexibility, cross sectional area). One of the key strands of this performance goal was to reduce the swimmers body mass, through a reduction in non-functional mass (i.e. fat mass). It was anticipated that a reduction in non-functional mass and consequently body mass would reduce the drag profile of the swimmer. This in turn would increase the swimmer's distance per stroke for any given stroke. While mass is not directly involved in the drag equation (see equation 1), a reduction in mass was proposed to reduce the drag coefficient (C_D) and cross-sectional area of the swimmer (A), reducing their drag profile.

$$F_{D=\frac{1}{2}\rho \upsilon^2 C_D \mathrm{A}}$$

F_D = Drag
p = Density of fluid (water in the pool)
v = Speed of the swimmer relative to the fluid
C_D = Drag coefficient
A = Cross sectional area
Equation 1. The drag equation [55]

As displayed in Table 2, goals one and two required greater levels of force production to push off the wall and improve speed. Therefore, the maintenance of lean mass was an important consideration when designing any periodised nutrition intervention.

A focus on body composition can cause anxiety among athletes [56] and may be associated with body dissatisfaction and symptoms of disordered eating and eating disorders [57]. To this extent, the swimmer was screened in September 2023 by the performance nutritionist as part of the Aquatics GB National Programme Screening Strategy, to ascertain their perceptions of body composition and the body composition assessment process. The swimmer was asked the following questions throughout the screening process: (1) "Do you want to monitor your body mass and composition in a structured way this season?"; (2) "Do you understand what this entails and why we may collect this data?"; (3) "Do you understand that by engaging in this process, we will assume continued consent to monitor as we have agreed?"; (4) "Do you understand the value of your support team being aware of some of this data from time to time?"; (5) "Do you understand that you can ask questions and change your views on monitoring at any time?". This was done to ensure that the swimmer was comfortable with the process, understood why the data may be collected, and how it may influence their performance (i.e. reduction in drag profile may increase distance per stroke). If there were any sensitives or feeling of anxiety or uncomfortableness towards the process, then the MDT team would not engage with monitoring this goal through body composition assessments, or the goal itself. The swimmer was comfortable with the process and understood the value of the data being collected. The swimmer was empowered to drive the monitoring process themselves (see section "Monitoring & Refinement") and therefore would request body composition assessments in consultation with the performance nutritionist and consequently, body composition monitoring was not enforced upon them.

Training Periodisation

Table 3 outlines a 'training session key' which was provided from the coach to the performance nutritionist, detailing a description of all the different types of training sessions which could be included in the swimmer's periodised training plan.

Table 4 outlines the training periodisation for the swimmer between the dates of Monday 3rd June to Sunday 14th July. This section of the mesocycle represented the swimmers final block of training, prior to entering the taper phase of their training on Monday 15th July. The swimmer competed in the 2024 Sette Colli swim meet in Rome, Italy during microcycle 3, racing in the three events across Friday, Saturday, and Sunday. As well as racing meters (e.g. 200 m), the swimmer would typically warm up for ~1000–1600 m and swim down for ~1000–1600 m for each race.

The performance nutritionist and coach 'RAG rated' each swimming session based on the energetic and glycolytic demands of the session (i.e. how much energy and glycogen are required to complete the session) as well as the physiological goal of the session (e.g. mitochondrial biogenesis, enhance buffering capacity etc.). The performance nutritionist then collaborated with the swimmer to get their perceptions of 'easy', 'moderate' and 'hard' sessions. Table 5 displays the RAG ratings of each session. Supplementary file 3 displays the document which

Table 3 Training session key

Training Session	Training Session Description
Recovery (R)	Very easy / light aerobic mix
Technical Recovery (TR)	Easy aerobic mix with technical focus
Aerobic Maintenance (AMT)	Moderate work to maintain aerobic fitness
Aerobic Development (ADEV)	Strong work to develop aerobic fitness
Aerobic > Technical (A > T)	Strong / short rest work to develop aerobic fitness
Strength Endurance (STEND)	Strong aerobic work with high resistance
Speed > Recovery (SP > R)	Session focusing on speed effort & mostly easy swimming
Speed > Aerobic Maintenance (SP > AMT)	Speed development and aerobic maintenance combination
Technical Pace (TP)	Technical, speed and pace work in preparation for key set or race
Speed > Resistance (SP > RES)	Endurance set which includes both resistance and speedwork
Speed > Endurance (SP > END)	Set starts / finishes with speed. However, the bulk of the set is endurance
Monocarboxylate Transporter 4 Race Pace 'Tempo (MCT4 RP Tempo)	Race pace set with softer design
Monocarboxylate Transporter 4 ~ Central Fartlek (MCT4 ~ Central Fartlek)	Race pace set – Progressive and challenging pattern with strong design
Monocarboxylate Transporter 4 Race Pace Pattern (MCT4 RP 'Pattern)	Race pace set – Progressive and challenging pattern with strong design
Monocarboxylate Transporter 4+1 Race Pace Combo (MCT4+1 RP 'Combo')	Race pace set & heart rate combination – Harder design
Aerobic Maintenance > Race (AMT > Race)	Aerobic block finishing with intense race / stand up swim
Monocarboxylate Transporter 4 Race Pace Simulation (MCT4 RP SIM)	Race pace work mimicking a competition
Monocarboxylate Transporter 1 (MCT1)	High intensity aerobic set which includes intensity close to race pace
Rainbow Set (RB)	Set which combines swimming at all intensities – Aerobic and anaerobic
Test Set (TS)	Either 7x200m step test or 4x [4x100 kick] best average
Kick and Pull (K+P)	Aerobic kick and pull
Gym (Gym)	Gym work as set by the strength and conditioning coach
Swim Bench (SB)	*n* reps at a specific watt output
Prime (P)	Land work primer in preparation for stand up swim or race effort

was created between the performance nutritionist and coach detailing the RAG rating of each training session.

Nutrition Periodisation Intervention & Plans

The performance nutritionist and swimmer underwent a 'scoping' session the week prior to starting the periodised nutrition plan, whereby the 'Periodised Nutrition System' was presented to the swimmer (e.g. repair plate, fuel plate, perform plate, sustain snacks, repair snacks), along with the rationale for this, and how best the swimmer would like the information presented. Supplementary file 1 displays the infographics presented to the swimmer during the scoping session. The swimmer was provided with approximately, 50 repair plate recipes, 50 fuel plate recipes, 50 perform plate recipes and a variety of different sustain snack and repair snack examples. To improve adherence to the 'Periodised Nutrition System', the swimmer outlined the 'types of meals' they would consume daily and collaborated with the performance nutritionist to develop some recipes which they could utilise (e.g. scrambled eggs on toast, peanut butter and jam bagel, cinnamon berry porridge bowl, miso salmon with wild rice, chicken and chorizo paella). These were formulated using the nutritional analysis software Nutritics (Nutritics Version 5, Nutritics Ltd, Ireland). Supplementary file 2 displays an example of a recipe card sent to the swimmer.

Tables 6, 7, 8, 9, 10, and 11 display the periodised nutrition plan for the swimmer for each microcycle, while supplementary file 4A-F show the periodised nutrition plan infographic that was sent to the swimmer. Microcycle 1 was intentionally planned and agreed in collaboration with the swimmer to be lower in kilocalories to 'gain momentum' with body mass loss during the intervention period. While chronic low energy availability may have a variety of negative health and performance outcomes, leading to relative energy deficiency in sport (REDS) [50], it was ensured that carbohydrates were cycled in prior to 'red sessions' so that the swimmer could sustain the required volume and intensity. After microcycle one, carbohydrate and overall kilocalorie intake was increased throughout microcycles two and three to reduce the risk of any physiological or performance related consequences such as REDS [50]. A body composition assessment was undertaken on the 18th June (Tuesday of microcycle 3). After discussion with the swimmer, they stated that they were happy with their composition from a

Table 4 The swimmer's training periodisation between Monday 3rd June to Sunday 14th July

Week		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week One: 3rd–9th June 2024 Week distance – 57.5km	**AM Session**	ADEV	TR + Gym	MCT1	ADEV + Gym	SP > END	STEND	Rest
	PM Session	MCT1	ADEV	Rest	TR	MCT4 RP SIM	Rest	Rest
Week Two: 10th–16th June 2024 Week distance – 57.5km	**AM Session**	ADEV	TR + Gym	STEND	Rest	SP > END	STEND	Rest
	PM Session	MCT1	ADEV	Rest	Gym + ADEV	MCT4 RP SIM	Rest	Rest
Week Three: 17th June-23rd June Week distance – 52km	**AM Session**	SP > END	SP > END	Travel	R	Race - Heats	Race - Heats	Race - Heats
	PM Session	TR	MCT1	Travel	TR + RACE WARM UP	Race - Final	Race - Final	Race - Final
Week Four: 24th June-30th June Week distance – 50-55km	**AM Session**	Travel	R + Gym	ADEV	SP > AMT + Gym	MCT4 RP SIM	STEND	Rest
	PM Session	Travel	SP > END	Rest	TR	MCT4 RP SIM	Rest	Rest
Week Five: 1st July-7th July Week distance – 60km	**AM Session**	AMT>SP + Gym	R	A>MT	ADEV + Gym	MCT4 RP SIM	STEND	Rest
	PM Session	MCT4 'Soft'	4x200 TT	Rest	TR	MCT4 RP SIM	Rest	Rest
Week Six: 8th July-14th July Week distance – 60km	**AM Session**	AMT > SP + Gym	R	A>MT	ADEV	MCT4 RP SIM	STEND	Rest
	PM Session	MCT4 RP TEMPO	MCT4 RP SIM	Rest	TR	MCT4 RP SIM	Rest	Rest

Table 5 RAG rating of each training session

RAG Rating	Description of RAG Rating	Training Sessions Description
Green (easy)	Main set = Approx. 50-40 beats below max heart rate; lactate < 2mmol·L^{-1}; low glycolytic demand	R; TR; AMT
Amber (Moderate)	Main set = Approx. 50-20 beats below max heart rate; speed work = lactate > 2 mmol·L^{-1}; aerobic and recovery elements = < 2 mmol·L^{-1}; moderate glycolytic demand Speed work programmed into these sessions is low in volume and therefore while glycogen is required to fuel the high intensity movements, this is not for a considerable period	ADev; A > T; StEnd; SP > R; SP > Amt; TP; SP > RES; SP > END; Kick and Pull K+P; Gym
Red (Hard)	Main set = Approx. 30-5 beats below max heart rate; lactate > 6 mmol·L^{-1}; high glycolytic demand	MCT4 RP Tempo; MCT4 ~ Central Fartlek; MCT4 RP 'Pattern; MCT4+1 RP 'Combo'; AMT > Race; MCT4 RP SIM; MCT1; RB; TS
Other	These sessions are traditionally low in volume and 'bolted' onto the start (e.g. primer) or incorporated into the session (e.g. swim bench)	SB; P

performance perspective and wanted to focus on 'fuelling effectively' during the upcoming swim meet (microcycle 3; Friday to Sunday), as well as the remainder of the mesocycle leading into the 2024 Paris Summer Olympic Games. Consequently, the focus of the intervention shifted from 'optimising aquatic profile' to 'optimising adaptations from training sessions' and the periodised nutrition plan was adjusted accordingly.

Monitoring & refinement

During the scoping session, the performance nutritionist presented all six microcycles of the periodised nutrition plan to the swimmer. The periodised nutrition plan for a particular microcycle was then sent to the swimmer on the Friday prior to the microcycle commencing the following Monday to refresh their memory and enable them to plan and prepare their nutrition strategies for the following week. This was accompanied by a face-to-face discussion with the nutritionist to discuss the 'flow' of nutrition periodisation for the microcycle, as well as reflections of the current microcycle (e.g. training performance, energy levels etc.). This discussion was cross-referenced with data collected by the MDT team. These were the following:

Table 6 Periodised nutrition plan for microcycle 1 from 3rd June 2024 to 9th June 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Fasted	Fasted	Sustain snack (40 g CHO)	Fasted	Sustain snack (40 g CHO)	Fasted	Repair snack
Training (AM)	**ADEV**	**TR + Gym**	**MCT1** Sustain snack (20g CHO)	**ADEV + Gym**	**SP > END**	**STEND**	
Post Swim (AM)	Repair snack	**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	Fuel plate	**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	Repair snack	Fuel plate	
Lunch	Fuel plate	Fuel plate	Repair snack	Fuel plate	Fuel plate	Repair snack	Fuel plate
Pre-Swim (PM)	Sustain snack (40 g CHO)	Sustain snack (40 g CHO)			Sustain snack (60 g CHO)		Repair snack
Training (PM)	**MCT1** Sustain snack (20 g CHO)	**ADEV**		**TR**	**MCT4 RP SIM** Sustain snack (20 g CHO)		
Dinner	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Perform plate	Fuel plate
Daily kcal and Macronutrient Targets							
Calories (kcal)	1450–2315	1450–2315	1450–2315	1290–2065	1530–2395	1410–2105	1515–2160
Carbohydrate (g / g·kg·bm^{-1})	160–270 / 2–3.5	160–270 / 2–3.5	160–270 / 2–3.5	120–230 / 1.5–3	180–290 / 2.3–3.8	150–260 / 1.9–3.4	100–220 / 1.3–2.9
Protein (g / g·kg·bm^{-1})	90–140 / 1.2–1.8	90–140 / 1.2–1.8	90–140 / 1.2–1.8	90–130 / 1.2–1.7	90–140 / 1.2–1.8	90–120 / 1.2–1.6	110–140 / 1.4–1.8
Fat (g / g·kg·bm^{-1})	50–75 / 0.6–1.0	50–75 / 0.6–1.0	50–75 / 0.6–1.0	50–70 / 0.6–0.9	50–75 / 0.6–1.0	50–65 / 0.6–0.8	50–80 / 0.6–1.0

Table 7 Periodised nutrition plan for microcycle 2 from 10th June 2024 to 16th June 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Fasted	Fasted	Sustain snack (20 g CHO)	Repair snack	Sustain snack (40 g CHO)	Fasted	Repair snack
Training (AM)	**ADEV**	**TR + Gym**	**STEND**		**SP > END**	**STEND**	
Post Swim (AM)	x1 Repair snack & x1 sustain snack (20 g CHO)	**PRE GYM** x1 Repair snack & x1 sustain snack (20 g CHO)	Fuel plate		x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	
Lunch	Fuel plate	Fuel plate	Repair snack	Fuel plate	Fuel plate	Fuel plate	Fuel plate
Pre-Swim (PM)	Sustain snack (60 g CHO)	Sustain snack (40g CHO)		Sustain snack (60 g CHO)	Sustain snack (80 g CHO)	Repair snack	Repair snack
Training (PM)	**MCT1** Sustain snack (20 g CHO)	**ADEV**		**Gym + ADEV**	**MCT4 RP SIM** Sustain snack (20 g CHO)		
Dinner	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate
Daily kcal and Macronutrient Targets							
Calories (kcal)	1810–2755	1650–2515	1490–2265	1650–2425	2050–3085	1570–2475	1490–2360
Carbohydrate (g / g·kg·bm^{-1})	250–360 / 3.2–4.7	210–320 / 2.7–4	170–280 / 2.2–3.6	210–320 / 2.7–4	310–420 / 4–5.5	170–290 / 2.2–3.7	150–270 / 1.9–3.5
Protein (g / g·kg·bm^{-1})	90–150 / 1.2–1.9	90–140 / 1.2–1.8	90–130 / 1.2–1.7	90–130 / 1.2–1.7	90–160 / 1.2–2.1	110–150 / 1.4–1.9	110–140 / 1.4–1.8
Fat (g / g·kg·bm^{-1})	50–80 / 0.6–1.0	50–75 / 0.6–1.0	50–70 / 0.6–0.9	50–70 / 0.6–0.9	50–85 / 0.6–1.1	50–80 / 0.6–1.0	50–80 / 0.6–1.0

Table 8 Periodised nutrition plan for microcycle 3 from 17th June 2024 to 23rd June 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Sustain snack (20 g CHO)	Sustain snack (20 g CHO)	Fuel plate*	Fuel plate*	Sustain snack (80 g CHO)	Sustain snack (80 g CHO)	Sustain snack (80 g CHO)
Training or Race (AM)	**SP > END + GYM**	**SP > END**		**R**	**Race - Heats**	**Race - Heats**	**Race - Heats**
Post Swim (AM)	**PRE GYM** x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)		x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (60 g CHO)	x1 Repair snack & x1 sustain snack (60 g CHO)	x1 Repair snack & x1 sustain snack (60 g CHO)
Lunch	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate
Pre-Swim (PM)		Sustain snack (60 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	Sustain snack (60 g CHO)	Sustain snack (80 g CHO)	Sustain snack (80 g CHO)	Sustain snack (80 g CHO)
Training or Race (PM)	**TR**	**MCT1**		**TR**	**Race - Final**	**Race - Final**	**Race - Final**
Post Race					x1 Repair snack & x1 sustain snack (60 g CHO)	x1 Repair snack & x1 sustain snack (60 g CHO)	x1 Repair snack & x1 sustain snack (60 g CHO)
Dinner	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate
Pre-Bed			Sleep strategy (20 g CHO)	Sleep strategy (20 g CHO)	Sleep strategy (20 g CHO)	Sleep strategy (20 g CHO)	Sleep strategy (20 g CHO)
Daily kcal and Macronutrient Targets							
Calories (kcal)	1570–2435	1810–2755	2075–3055	2315–3375	2690–3980	2690–3980	2690–3980
Carbohydrate (g / g·kg·bm^{-1})	190–300 / 2.5–4	250–360 / 3.3–4.8	240–400 / 3.2–5.3	300–460 / 4–6.1	450–590 / 5.8–7.6	450–590 / 5.8–7.6	450–590 / 5.8–7.6
Protein (g / g·kg·bm^{-1})	90–140 / 1.2–1.9	90–150 / 1.2–2	110–150 / 1.5–2	110–160 / 1.5–2.1	110–180 / 1.5–2.4	110–180 / 1.5–2.4	110–180 / 1.5–2.4
Fat (g / g·kg·bm^{-1})	50–75 / 0.7–1.0	50–80 / 0.7–1.1	75–95 / 1–1.3	75–100 / 1–1.3	50–100 / 0.7–1.3	50–100 / 0.7–1.3	50–100 / 0.7–1.3

Capillary blood samples

Capillary Blood samples were collected during key sessions (e.g. MCT4 RP SIM) and analysed for blood lactate quantity. Capillary blood samples were primarily taken by the Aquatics GB physiologist using the ear prick technique. Briefly, the ear lobe was cleaned using an alcohol wipe, before a lancet was utilised to prick the earlobe. The first blood drop was wiped away before a Lactate Pro 2 Sports Blood Lactate Meter (Arkray, Kyota, Japan) and Lactate Pro 2 Test strip (Arkray, Kyota, Japan) were used to collect a capillary blood sample, and consequently blood lactate measurement. The Lactate Pro 2 Sports Blood Lactate Meter has been shown to have high reliability (intraclass correlation coefficient [ICC] = 0.99), although displays poor construct validity in comparison to a calibrated laboratory-based analyser at high intensities (intraclass correlation coefficient at 4.1–8.0 mmol·L^{-1} = 0.30) [58]. Unfortunately, a laboratory-based analyser was not available to analyse blood lactate samples and is a potential limitation of the data collection process.

Countermovement jumps

Countermovement jumps were included to quantify neuromuscular fatigue [59]. These were conducted during the first gym session of each microcycle by the Aquatics GB strength and conditioning coach. Briefly, the swimmer would stand on a force plate (Vald Performance, Quensland, New Zealand), before being instructed to perform a countermovement jump while keeping their arms on their hips for the duration of the protocol.

Rating of perceived exertion

Rating of perceived exertion (RPE) was quantified via the Foster modified CR10 Scale after each completed session (n/10) [60]. The swimmer inputted their RPE onto a Google Docs form (Google, California, USA), which was then exported and saved on a Microsoft Excel spreadsheet (Microsoft, Washington, USA). The swimmer was educated on how to interpret the Foster modified CR10 Scale prior to collecting any data to increase the validity of the data.

Table 9 Periodised nutrition plan for microcycle 4 from 24th June 2024 to 30th June 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Fuel plate*	Fasted	Sustain snack (20 g CHO)	Sustain snack (40 g CHO)	Sustain snack (60 g CHO)	Sustain snack (20 g CHO)	Repair snack
Training (AM)		**R + Gym**	**ADEV**	**SP > AMT + Gym**	**MCT4 RP SIM** x1 sustain snack (20 g CHO)	**STEND**	
Post Swim (AM)		**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	Fuel plate	x1 Repair snack	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	
Lunch	Fuel plate	Fuel plate	x1 Repair snack	Fuel plate	Fuel plate	Fuel plate	Fuel plate
Pre-Swim (PM)	x1 Repair snack	Sustain snack (60 g CHO)		Sustain snack (40 g CHO)	Sustain snack (80 g CHO)	Repair snack	Repair snack
Training (PM)		**SP > END**		**TR**	**MCT4 RP SIM** x1 sustain snack (20 g CHO)		
Dinner	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate
Daily kcal and Macronutrient Targets							
Calories (kcal)	1915–2810	1730–2595	1490–2270	1730–2595	2210–3330	1650–2645	1490–2315
Carbohydrate (g / g·kg·bm^{-1})	200–360 / 2.7–4.8	230–340 / 3.1–4.5	170–280 / 2.3–3.7	230–340 / 3.1–4.5	350–460 / 4.7–6.1	190–310 / 2.5–4.1	150–270 / 1.9–3.5
Protein (g / g·kg·bm^{-1})	110–140 / 1.5–1.9	90–140 / 1.2–1.9	90–130 / 1.2–1.7	90–140 / 1.2–1.9	90–170 / 1.2–2.3	110–160 / 1.5–2.1	110–140 / 1.4–1.8
Fat (g / g·kg·bm^{-1})	75–90 / 1–1.2	50–75 / 0.7–1.0	50–70 / 0.7–0.9	50–75 / 0.7–0.9	50–90 / 0.7–1.1.2	50–85 / 0.7–1.1	50–75 / 0.6–1.0

Table 10 Periodised nutrition plan for microcycle 5 from 1st July 2024 to 7th July 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Sustain snack (40 g CHO)	Fasted	Fasted	Sustain snack (20 g CHO)	Sustain snack (60 g CHO)	Sustain snack (20 g CHO)	Repair snack
Training (AM)	**AMT > SP + Gym**	**R**	**A>MT**	**ADEV + Gym**	**MCT4 RP SIM** x1 sustain snack (20 g CHO)	**STEND**	
Post Swim (AM)	**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack	**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	
Lunch	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate
Pre-Swim (PM)	Sustain snack (60 g CHO)	Sustain snack (80 g CHO)			Sustain snack (80 g CHO)	Repair snack	Repair snack
Training (PM)	**MCT4 'Tempo'** x1 sustain snack (20 g CHO)	**MCT4 RP SIM** x1 sustain snack (20 g CHO)		**TR**	**MCT4 RP SIM** x1 sustain snack (20 g CHO)		
Dinner	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate
Daily kcal and Macronutrient Targets							
Calories (kcal)	1970–3005	1890–3020	1410–2105	1570–2435	2210–3290	1650–2645	1490–2315
Carbohydrate (g / g·kg·bm^{-1})	290–400 / 3.9–5.3	270–380 / 3.6–5.1	150–260 / 2–3.5	190–300 / 2.5–4	350–460 / 4.7–6.1	190–310 / 2.5–4.1	150–270 / 1.9–3.5
Protein (g / g·kg·bm^{-1})	90–160 / 1.2–2.1	90–150 / 1.2–2	90–120 / 1.2–1.6	90–140 / 1.2–1.9	90–160 / 1.2–2.1	110–160 / 1.5–2.1	110–140 / 1.4–1.8
Fat (g / g·kg·bm^{-1})	50–85 / 0.7–1.1	50–80 / 0.7–1.1	50–65 / 0.7–0.9	50–75 / 0.7–1.0	50–90 / 0.7–1.2	50–85 / 0.7–1.1	50–75 / 0.6–1.0

Table 11 Periodised nutrition plan for microcycle 6 from 8st July 2024 to 14th July 2024

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-Swim (AM)	Sustain snack (40g CHO)	Fasted	Fasted	Sustain snack (20g CHO)	Sustain snack (60g CHO)	Sustain snack (20g CHO)	Repair snack
Training (AM)	**AMT > SP + Gym**	**R**	**A>MT**	**ADEV**	**MCT4 RP SIM** x1 sustain snack (20g CHO)	**STEND**	
Post Swim (AM)	**PRE GYM:** x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	x1 Repair snack & x1 sustain snack (20 g CHO)	
Lunch	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate	Fuel plate
Pre-Swim (PM)	Sustain snack (60 g CHO)	Sustain snack (80 g CHO)			Sustain snack (80 g CHO)	Repair snack	Repair snack
Training (PM)	**MCT4 RP TEMPO** x1 sustain snack (20 g CHO)	**MCT4 RP SIM** x1 sustain snack (20 g CHO)		**TR**	**MCT4 RP SIM** x1 sustain snack (20 g CHO)		
Dinner	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate	Perform plate
Daily Kcal and Macronutrient Targets							
Calories (kcal)	1970–3005	1890–3020	1410–2105	1570–2435	2210–3290	1650–2645	1490–2315
Carbohydrate (g / g·kg·bm^{-1})	290–400 / 3.9–5.3	270–380 / 3.6–5.1	150–260 / 2–3.5	190–300 / 2.5–4	350–460 / 4.7–6.1	190–310 / 2.5–4.1	150–270 / 1.9–3.5
Protein (g / g·kg·bm^{-1})	90–160 / 1.2–2.1	90–150 / 1.2–2	90–120 / 1.2–1.6	90–140 / 1.2–1.9	90–160 / 1.2–2.1	110–160 / 1.5–2.1	110–140 / 1.4–1.8
Fat (g / g·kg·bm^{-1})	50–85 / 0.7–1.1	50–80 / 0.7–1.1	50–65 / 0.7–0.9	50–75 / 0.7–1.0	50–90 / 0.7–1.2	50–85 / 0.7–1.1	50–75 / 0.6–1.0

Wellness data

Wellness data for energy levels, sleep quality, and muscle soreness was collected daily (including rest days) throughout the duration of the mesocycle, with these being rated out of 10 (n/10). These were collected by the coach, with the swimmer inputting their data onto a Google Docs form, which was then exported and saved on a Microsoft Excel spreadsheet.

Team meetings and anecdotal feedback

Anecdotal feedback during multi-disciplinary team meetings or one-to-one conversations with the coach or member of the MDT team were collected. This was utilised to determine the extent to which either the training periodisation or the periodised nutrition plan needed to be adjusted based on the feedback sources. Twice-weekly meetings between the coach and MDT team were also held to discuss the performance of the swimmer and any adjustments to the training periodisation.

Body composition assessments

The swimmer was empowered to take ownership of the periodised nutrition plan and monitoring process. During the scoping session, the swimmer outlined when they wanted body composition assessments to be undertaken in agreement with the performance nutritionist (measurement one = 3rd June, measurement two = 18th June, measurement three = 16th July). Body composition was taken by the performance nutritionist and quantified through the sum of eight skinfold method, using Harpenden skinfold callipers (Harpenden Ltd, Harpenden, UK), according to the International Society for the Advancement of Kinanthropometry (ISAK) guidelines [61]. The performance nutritionist was an ISAK level one practitioner. Two measurements were taken for each site, with a third being taken if the first two measurements had a variability greater than 10%, as per ISAK level one practitioner guidelines. The mean value was recorded where two measurements were collected, with the median being reported where three measurements were taken. The nutritionist had an ICC of 0.99 during measurement one, an ICC of 0.99 during measurement two, and an ICC of 0.99 during measurement three. Sum of 8 skinfold method has been shown to be a valid and reliable method when working in the field [62]. Relaxed arm, waist, glute, thigh and calf girth were also collected. This was also collected according to ISAK guidelines. Briefly, an anthropometric tape measure (Lufkin W606PD, Lufkin, Cleveland, USA) was wrapped around the marked anthropometric site (e.g. waist) and the value was recorded. One measurement was taken for each anthropometric site. The swimmer stated that they did not value collecting body mass data on a frequent basis as this added 'noise' to the goal due to daily fluctuations in mass caused through glycogen, hydration status and female sex hormones such as oestrogen [63]. Therefore, body mass was only collected when quantifying body composition using Seca 875 Scales (Seca, GmBH, Hamburg, Germany). A prediction equation was calculated to quantify the swimmer's predicted lean mass and predicted fat mass as reported by Van Der Ploeg et al., (2003) [64]. At each body composition monitoring session, the swimmer was re-familiarised with the data collection process, given ample opportunity to ask any questions, or refuse the process.

Self-Reported food diaries

Four-day self-reported food diaries were also completed by the swimmer on two separate occasions (4th to 7th June and 25th to 28th June) to ensure that the swimmer was on track, and energy intake was consistent with what was being advised in the periodised nutrition plan. Food diaries were completed through a combination of the weighed food method [65] and Snap'N'Send [66]. Briefly, the swimmer would send across a picture and description of any food or drink they consumed (i.e. name of food, ingredients and quantity, cooking methods etc.) upon consuming to ensure this was timestamped. Upon completion of each four-day food diary, food diaries were analysed by the performance nutritionist using the nutrition analysis software Nutritics (Nutritics Version 5, Nutritics Ltd, Ireland). Energy intake was reported in kilocalories (kcals) and macronutrient intakes were analysed and reported in grams (g) and grams per kilogram of body mass ($g \cdot kg \cdot bm^{-1}$).

Intervention outcomes

Capillary blood samples

Tables 12, 13, 14, 15, 16 and 17 displays peak blood lactate quantity (i.e. highest blood lactate quantity experienced throughout the session) collected from a capillary blood sample. Capillary blood samples were taken during some 'amber' sessions (e.g. SP > END), all 'red' sessions (see table 5) and finals of races (such as in microcycle 3).

Table 12 Blood lactate quantity during training sessions in Microcycle 1 from 3rd to 9th June 2024

	Session 1	Session 2	Session 3	Session 4
Training Session (Predicted Peak Blood Lactate [$mmol \cdot L^{-1}$])	MCT1 (6–12)	MCT1 (6–12)	SP > END (2–6)	MCT4 RP SIM (>12)
Peak Blood Lactate ($mmol \cdot L^{-1}$)	10.4	11.6	5.2	12.7

Table 13 Blood lactate quantity during training sessions in Microcycle 2 from 10th to 16th June 2024

	Session 1	Session 2	Session 3
Training Session (Predicted Peak Blood Lactate [$mmol \cdot L^{-1}$])	MCT1 (6–12)	SP > END (2–6)	MCT4 RP SIM (>12)
Peak Blood Lactate ($mmol \cdot L^{-1}$)	9.5	4.8	13.4

Body Composition

Table 18 displays the body composition data collected throughout the periodised nutrition intervention. Over an 18-day period of the 'optimising aquatic profile' phase of the intervention, there was a 2.1 kg decrease in body mass, an 18.1 mm reduction in sum of 8 skinfolds, a 0.1 kg decrease in predicted lean mass and a 2.2 kg decrease in predicted fat mass. Over the remainder of the mesocycle and the 'optimising adaptations from training sessions' phase, there was a 0.2 kg increase in body mass, a 2 mm reduction in sum of 8 skinfolds, a 0.7 kg increase in predicted lean mass and 0.5 kg decrease in predicted fat mass.

Table 19 presents the girth measurements collected throughout the periodised nutrition intervention. There was a reduction in all anthropometric sites throughout the intervention.

Food diary

Table 20 displays the food diary data collected during microcycle one (Tuesday 4th June to Friday 7th June), while Table 21 shows the food diary data collected during microcycle four (Tuesday 25th June to Friday 28th June).

During microcycle one, fat intake was slightly greater than planned due to the swimmer using high amounts of olive oil while cooking. Despite olive oil having numerous health benefits [67], this was tweaked to ensure the swimmer stayed within the macronutrient guidance. During microcycle 4, the swimmer was within the planned nutrition periodisation targets for all days.

Discussion & Practitioner reflections

The aim of this case study was to (1) propose a 'Periodised Nutrition System' which can be utilised by nutritionists when working with athletes; (2) discuss how this can be administered in practice, collaborating with the coach, multidisciplinary team and athlete; (3) present a case

Table 14 Blood lactate quantity during training sessions in Microcycle 3 from 17th to 23rd June 2024

	Session 1	Session 2	Session 3	Session 4
Training Session (Predicted Peak Blood Lactate [mmol·L^{-1}])	MCT1 (6–12)	Race – Final* (>12)	Race – Final* (>12)	Race – Final* (>12)
Peak Blood Lactate (mmol·L^{-1})	10.1	18.5	16.7	19.3

* Indicates when sodium bicarbonate (Maurten AB, Gothenburg, Sweden) was consumed prior to session

Table 15 Blood lactate quantity during training sessions in Microcycle 4 from 24th to 30th June 2024

	Session 1	Session 2	Session 3	Session 4
Training Session (Predicted Peak Blood Lactate [mmol·L^{-1}])	SP > END (2–6)	MCT4 RP SIM (>12)	MCT4 RP SIM* (>12)	
Peak Blood Lactate (mmol·L^{-1})	4.2	14.6	16.9	

* Indicates when sodium bicarbonate (Maurten AB, Gothenburg, Sweden) was consumed prior to session

Table 16 Blood lactate quantity during training sessions in Microcycle 5 from 1st to 7th July 2024

	Session 1	Session 2	Session 3	Session 4
Training Session (Predicted Peak Blood Lactate [mmol·L^{-1}])	**MCT4 'Tempo' (6–12)**	**4x200 TT (>12)**	**MCT4 RP SIM (>12)**	**MCT4 RP SIM* (>12)**
Peak Blood Lactate (mmol·L^{-1})	10.8	13.1	13.8	15.1

* Indicates when sodium bicarbonate (Maurten AB, Gothenburg, Sweden) was consumed prior to session

study of the proposed 'Periodised Nutrition System' and its utilisation with a world class swimmer in the build-up to the 2024 Paris Summer Olympic Games. Stellingwerff et al., (2019) [11] stated that there needs to be better quantification of knowledge and application of nutritional periodisation approaches among athletes. While previous literature has proposed various tools to enable athletes to periodise their nutrition, such as periodisation approaches [11], colour coded frameworks [37, 39], and educational plate tools [47], to the authors knowledge, this is the first proposed 'Periodised Nutrition System' in the scientific literature, conveying how different 'performance plates' can be utilised to sit in tandem with an athletes training periodisation in a real-world scenario. This case study presents the 'Periodised Nutrition System', proposing different 'performance plates', quantities of different foods to fit into the 'performance plates' to aid recipe development, and how they may practically fit into an athlete's periodisation alongside theoretical rationale. This will hopefully generate some meaningful discussion among practitioners and academics to critique the proposed 'Periodised Nutrition System' and enable other practitioners to share their understanding and application of nutritional periodisation approaches within a variety of sports.

While the 'Periodised Nutrition System' provides a template for practitioners to utilise to deliver periodised nutrition support to an athlete, simply applying a 'copy and paste' approach is sub optimal. This case study highlights an array of skills a nutritionist needs to embed a periodised approach when supporting elite athletes. A performance nutritionist must have sufficient technical knowledge to understand the underpinning physiological and technical demands of the sport as well as the intended physiological responses from different sessions (e.g. aerobic development vs. MCT4 RP SIM) to ensure that the athlete is able to work at the correct intensity, utilising the intended fuel source, maximising the adaptive response. They must also be able to accurately predict the energy expenditure of the athlete so that the recommendations of the nutrition periodisation plan are appropriate. The performance nutritionist must also possess a variety of 'soft' skills such as: being able to effectively communicate with the coach, MDT team, and

Table 17 Blood lactate quantity during training sessions in Microcycle 6 from 8th to 14th July 2024

	Session 1	Session 2	Session 3	Session 4
Training Session (Predicted Peak Blood Lactate [mmol·L^{-1}])	**MCT4 RP TEMPO (6–12)**	**MCT4 RP SIM (>12)**	**MCT4 RP SIM* (>12)**	**MCT4 RP SIM* (>12)**
Peak Blood Lactate (mmol·L^{-1})	8.8	13.3	14.2	15.7

* Indicates when sodium bicarbonate (Maurten AB, Gothenburg, Sweden) was consumed prior to session

Table 18 Swimmer's body composition data throughout the periodised nutrition intervention

Date	Body mass (kg)	Sum of 8 Skinfolds (mm)	Predicted Lean Mass (kg)	Predicted Fat Mass (kg)
31/05/24	76.9	98.3	63.1	13.9
18/06/24	74.8	80.2	63.0	11.7
16/07/24	75.0	78.2	63.7	11.3

Table 19 Swimmer's girth data throughout the periodised nutrition intervention

Date	Arm Relaxed (cm)	Waist (cm)	Glutes (cm)	Thigh (cm)	Calf (cm)
31/05/24	31.5	74.5	102.5	58.8	36.3
18/06/24	31.1	73.1	99.6	57.5	36.2
16/07/24	30.5	72.8	100.5	57.5	36.1

Table 20 Swimmer's food self-reported diary data collected during microcycle one

Date	Kilocalories (kcal)	Carbohydrate (g) / (g.kg.bm^{-1})	Protein (g) / (g.kg.bm^{-1})	Fat (g) / (g.kg.bm^{-1})
04/06/24	1783	214 / 2.8	126 / 1.6	42 / 0.5
05/06/24	2178	237 / 3.1	118 / 1.5	84 / 1.1
06/06/24	2315	243 / 3.2	137 / 1.8	91 / 1.2
07/06/24	2369	261 / 3.4	141 / 1.8	84 / 1.1

Table 21 Swimmer's food self-reported diary data collected during microcycle four

Date	Kilocalories (kcal)	Carbohydrate (g) / (g.kg.bm^{-1})	Protein (g) / (g.kg.bm^{-1})	Fat (g) / (g.kg.bm^{-1})
25/06/24	2001	246 / 3.3	103 / 1.4	67 / 0.9
26/06/24	2050	220 / 2.9	134 / 1.8	71 / 0.9
27/06/24	1746	214 / 2.9	107 / 1.4	51 / 0.7
28/06/24	2733	396 / 5.3	132 / 1.8	69 / 0.9

athlete to establish performance strategies and feedback interventions to key stakeholders; time management to ensure periodisation plans are delivered on time; team work and collaborative skills to work as part of an MDT team, gaining feedback (such as blood lactate data from capillary blood samples; see Tables 7A-7F) to inform the whether the nutrition periodisation needs adjusting; and creativity to package up the periodised nutrition plan in a way that is appropriate for the athlete so they can follow (such as supplementary files 1, 2, and 4A-F).

Previous research has highlighted that there may be little planning and integration of training prescription and nutrition between the performance nutritionist and multi-disciplinary team [10]. An advantage of adopting a periodised nutrition approach with athletes on a microcycle basis is that it enables practitioners to align nutrition support to the individual, their performance goal(s) and the desired adaptation of each training session. Following the process of how to embed the 'Periodised Nutrition System' (Figure 1) can add structure and greater alignment of training and nutrition periodisation between key stakeholders. Reflective practice is a key skill for a performance nutritionist to develop [68, 69]. Some key reflections from the performance nutritionist were that they had a greater understanding of the athletes training periodisation as they were specifically programming the nutrition periodisation alongside. As the performance nutritionist had an awareness of the swimmers training periodisation, they were able to greater embed nutritional strategies such as the swimmer practicing their racing nutrition strategies prior to MCT4 RP SIM sessions (see microcycles 4, 5, and 6). This included refining their pre-race meal alongside the addition of racing supplements such as nitrates [70], caffeine [71] and sodium bicarbonate [72], ensuring gastrointestinal issues were minimised. By having greater awareness of the training periodisation, the performance nutritionist can be proactive in their guidance rather than being reactive, achieving a greater level of collaboration with the athlete.

While this case study has focused on macronutrients, the 'Periodised Nutrition System' is a tool to ensure that the athlete has structure and purpose to their nutrition, aligned with their training periodisation. The 'Periodised Nutrition System' enables an initial structure for this to develop organically between the performance nutritionist and athlete. Different performance strategies can be layered alongside such as: creating nitrate rich 'repair', 'fuel' and 'perform' plates to increase nitric oxide storage in the muscle [70]; the addition of creatine monohydrate to increase glycogen synthesis if the athlete is undergoing high training loads whereby high carbohydrate availability is required [44]; or the supplementation of specific micronutrients, such as iron when an athlete is training at altitude [41]. This will depend on how the performance nutritionist applies their knowledge and skills to package up the nutrition support and layer on their performance strategies.

A potential negative of embedding a periodised nutrition approach is that athletes may look at nutrition 'mathematically', simply looking at the nutritional value of food, how much energy and the macronutrient composition of it. This goes against the essence that food is there to be enjoyed and is a mechanism for connecting people and communities [73] and is not the intention of the 'Periodised Nutrition System'. To this extent, the nutritionist collaborated with the swimmer to 'flex' their periodisation to facilitate 'social engagements' and 'meals out'. Feedback provided from the swimmer was that this was empowering, as there was no 'guilt' attached to social engagements as these were planned, and there was clarity between the performance nutritionist and swimmer. This does highlight a limitation of the 'Periodised Nutrition System', that while you can have a plan, it is impossible to be 100 % sure how much energy an athlete is consuming. Similarly, across the repair, fuel, and perform plates, fat is fixed at ~25 g. However, when consuming a 'takeaway meal' or 'eating out' this is likely to be more than this. Another limitation may be that the daily energy and macronutrient targets appear to have a wide range (i.e. ~1000 kcal; ~100–150 g CHO; ~50 g PRO; ~30 g FAT). If an athlete was to consistently consume the lower end of this target, energy intake may not be sufficient, whereas if they were to consume the higher end this may be too much. An athlete consumes food, containing a combination of all three macronutrients, and from the authors experience, athletes tend to consume in the middle of these recommendations (see table 10B). An example in practice may be a 'sustain snack' which is recommended to contain 20–60 g CHO, 0–10 g PRO and 0–10 g FAT. However, when translated to food this could be x2 Weetabix with 150 ml semi skimmed milk which contains 209 kcal, 33 g CHO, 10 g PRO, and 3 g FAT. It is unlikely that an athlete would ever consume at the lower end of the suggested range (e.g. 0 g PRO; 0 g FAT) unless they consumed high amounts of non-food products such as sports gels and protein powders which generally contain high amounts of one macronutrient but limited amounts of other macronutrients. The authors also acknowledge that the 'Periodised Nutrition System' is not an exact science. Indeed, there are many variables which can influence the process such as the accurately estimating of energy expenditure, while there are also discrepancies in the monitoring process such as inaccurate food diaries. Therefore, the 'Periodised Nutrition System' should be looked at as a tool to enable practitioners to better align their nutritional strategies with the training periodisation of an athlete and help the athlete to develop a structure to their nutrition strategies.

Future research recommendations

Future research should aim to apply the 'Periodised Nutrition System' in other cohorts of athletes and sports to determine its validity. The case study demonstrates how the 'Periodised Nutrition System' has supported three goals of a world class swimmer throughout a mesocycle: (1) optimising aquatic profile (microcycles 1–3); (2) racing nutrition (microcycle 3); (3) maximising training adaptations (microcycles 4–6). A limitation is of the 'Periodised Nutrition System' is that it hasn't been utilised in a hypertrophy or team sport scenario. Therefore, whether the 'Periodised Nutrition System' would be appropriate for a Rugby Union player aiming to increase lean mass as an example remains to be seen.

An understanding of behaviour change science is becoming recognised as an important consideration for performance nutritionists [74]. Reflections from the swimmer referenced a greater adherence to nutritional strategies as the periodisation was bespoke to their training periodisation and their performance goal(s). They felt more motivated to include monitoring tools such as food diaries and complete them more accurately as they valued the data so that they could make appropriate adjustments if required. The performance nutritionist also experienced an increase in communication with the swimmer, most likely due to embedding the 'Periodised Nutrition System' and following an athlete centred approach, empowering them to drive the process, increasing the athlete's motivation. Consequently, future research should aim to capture any behaviour changes which occur when utilising the 'Periodised Nutrition System'.

Conclusions

The purpose of this case study was to (1) propose a 'Periodised Nutrition System' which can be utilised by nutritionists when working with athletes; (2) discuss how this can be administered in practice, collaborating with the coach, multidisciplinary team and athlete; (3) present a case study of the proposed 'Periodised Nutrition System' and its utilisation with a world class swimmer in the build-up to the 2024 Paris Summer Olympic Games. Previous research has highlighted that performance nutritionists can typically work in isolation, and this can potentially leading to little planning and integration of training prescription and nutrition between the nutritionist and multi-disciplinary team [10]. To this extent, the 'Periodised Nutrition System' enables the practitioner to develop structure to their support aligning nutritional strategies with the training periodisation of the athlete, allowing for an individual approach, specific to the athlete's performance goal(s) and the desired adaptation of a training session. Future research should determine the 'Periodised Nutrition Systems' validity in a variety of other athletes and sports as well as capturing any behaviour change tools utilised to optimise nutrition support provided to athletes.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3

Supplementary Material 4.

Supplementary Material 5

Supplementary Material 6.

Supplementary Material 7.

Supplementary Material 8.

Supplementary Material 9.

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Authors' contributions
O Turner, N Mitchell, and R Chessor developed the 'Periodised Nutrition System'. O Turner provided nutrition support to the world class swimmer. O Turner drafted the manuscript and oversaw manuscript preparation. N Mitchell and R Chessor assisted with revising the manuscript. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The swimmer and coach were informed about the purpose of the support provision, and the first author answered any questions had. Written informed consent which adopted the ethical principles described by Sheffield Hallam University Ethics Committee was provided by the athlete and coach, and consequently both provided consent for the publication of this case study.

Consent for publication
The swimmer and coach were informed about the purpose of the support provision, and the first author answered any questions had. Written informed consent which adopted the ethical principles described by Sheffield Hallam University Ethics Committee was provided by the athlete and coach, and consequently both provided consent for the publication of this case study.

Competing Interests
The authors declare no competing interests.

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