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PhD Exercise Science

Balancing Carbohydrates and Fats: A Dual Approach to Fuelling Endurance Exercise.

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Wow, what a ride!

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List of Abbreviations and Symbols

ATP – Adenosine triphosphate

BHB – Beta-Hydroxybutyrate

BMR – Basil Metabolic Rate

CHO - Carbohydrates

CV – Coefficient of variation

ETC – Electron Transport Chain

FFA – Free fatty acids

FFQ – Food frequency questionnaire

GI – Gastrointestinal

HR – Heart rate

HF – High-fat

HC – High carbohydrate

IOM - The Food and Nutrition Board of the Institutes of Medicine

LCHF – Low-carbohydrate-high-fat

HCLF – High-carbohydrate-low-fat

LCT – Long-chain triglycerides

MCT – Medium-chain triglycerides

O_2 – Oxygen

PTRS – Peak treadmill running speed test

RER – Respiratory exchange ratio

RPE – Rating of perceived exertion

RST – Repeated sprint test

SD – Standard deviation

TEF – Thermic effect of food

TTE – Time till exhaustion

VCO_2 – Carbon dioxide production

VO_2 – Oxygen consumption

$\dot{V}O_2max$ – Maximal oxygen consumption

Abstract

Endurance running requires precise nutritional strategies to meet energy requirements and optimize performance. Both carbohydrates (CHO) and fats play crucial roles in fuelling prolonged exercise, with their interaction influencing energy availability and efficiency during exercise. Recognizing these dynamics is essential for improving athletic outcomes. This PhD explores the roles of CHO and fats, focusing on their individual and combined utilization to optimize running performance. The thesis includes a scoping review, an experimental trial, and an observational, descriptive study to provide a holistic view of endurance nutrition. **Methods:** The scoping review systematically analysed medium-chain triglycerides (MCT) and their impact on endurance performance across studies, identifying critical gaps in methodologies and limited application in runners. The experimental trial employed a randomized crossover design to compare the effects of CHO (10%), MCT (4.3%), or MCT+CHO (4.3% + 10%) supplements in trained endurance runners during a 90-minute steady-state run at 75% Peak Treadmill Speed (PTS) followed by a 5km time-trial (TT). Outcomes measured included substrate utilization, oxygen consumption (VO_2), heart rate (HR), rate of perceived exertion (RPE), gut discomfort, glucose, beta-hydroxybutyrate (BHB), glycerol, free-fatty acids (FFA) and lactate concentrations, and TT finishing times. In the observational, descriptive study, South African marathon runners from two cohorts (2014 and 2024) provided information on dietary habits and training logs to evaluate macronutrient and energy intake, energy expenditure, energy balance, and macronutrient distribution in the month before a marathon, as well as CHO and fat-loading strategies used on the days immediately before a marathon. **Results:** The scoping review emphasized limited research on the effects of MCT in runners and females, identifying only two studies conducted on runners and none on female athletes. The review highlights the need for future runner-specific research on the effects of MCT on running performance. Additionally, the review underpinned the potential benefit of combining MCT with CHO to improve performance. The experimental trial revealed that the use of CHO reduced GI discomfort compared to the MCT group (0.4 ± 0.9 and 1.6 ± 1.9, respectively) ($p = 0.0001$), and resulted in the lowest HR (151 ± 11, 154 ± 11 and 155 ± 11 bpm for MCT+CHO, MCT, and CHO groups, respectively) and RPE (5.9 ± 1.3, 6.1 ± 1.1 and 6.5 ± 1.1 for MCT+CHO, CHO, and MCT, respectively) during the 90-minute steady run. The observational study found that a balanced diet of 46-52% CHO, 16-17% protein, and 29-34% fat best described the macronutrient intake of marathon runners. Additionally, an equal energy balance was noted between daily energy intake and expenditure. Daily intake of CHO relative to body

weight was substantially low compared to recommended levels for endurance athletes (< 5 $g.kg^{-1}.day^{-1}$ compared to recommendations of 8-12 $g.kg^{-1}.day^{-1}$). When comparing the data from 2014-2024, there was a notable increase in daily fat intake ($p < 0.001$). Additionally, the study found 59-63% of runners CHO-load on the days before an event, whilst only 3-6% chose to fat-load. Finally, the study found that marathon runners were less likely to purposely restrict their fat intake in 2024 than in 2014. **Conclusion:** Although the combination of MCT and CHO shows potential to improve endurance performance, this was not the case in the experimental study. Combining MCT+CHO did not affect TT performance; however, it did result in reduced HR, and RPE. The addition of MCT to CHO aligns with the current dietary habits of marathon runners, who now habitually consume more fat compared to a decade ago. Finally, the low CHO intake observed in marathon runners warrants further investigation to identify the reasons for not meeting the recommended guidelines. Educating runners on the importance of adequate CHO intake for optimizing training and performance is essential

Chapter One: Thesis Introduction

The relationship between nutrition and exercise performance is a complex and multifaceted area of study that has received significant attention in sports science and exercise physiology. Understanding how different macronutrients, such as carbohydrates (CHO) and fats, affect energy production and overall athletic performance is crucial for developing optimal dietary strategies for athletes and individuals engaged in regular physical activity [1–3].

The current viewpoint in sports nutrition is in support of the use of CHO before [4–6], during [7,8], and after exercise [9–11] to enable adequate fuel sources of endogenous (produced or stored within the body) and exogenous (obtained from outside the body, commonly through diet) fuel. This is supported by decades of research conducted during moderate to long-duration aerobic exercise, such as running and cycling [8,12–16]. Long-distance events, lasting 90 minutes or longer, require in-depth fuelling strategies, where CHO intake during exercise has been instrumental in improving performance. Despite clear recommendations, runners often under-consume CHO, resulting in inadequate glycogen stores [11,14,17–19]. Even for those who meet CHO recommendations and achieve supercompensation of muscle glycogen, depletion is unavoidable during long-duration exercise, leading to fatigue [11,14,17–19]. To hasten fatigue, alternate dietary strategies to sustain endurance exercise have been investigated, most commonly with the use of exogenous fats [20].

The research on the use of exogenous fats includes following a high-fat (HF) diet for weeks before an event or consuming HF meals or supplements immediately before exercise, as well as HF supplements during exercise. Such supplements include the use of medium-chain triglycerides (MCT) [20–25]. However, none of the above shows conclusive evidence that fats in any form can be as effective as CHO supplementation in improving exercise performance. Nonetheless, limited research suggests combining long-term high-fat intake (2-4 weeks) with short-term CHO-loading (2-3 days before an event) may enhance exercise performance. [26,27]. Furthermore, combining CHO with MCT supplementation directly before and during exercise shows potential for improving TT performance [15,28–30].

To this end, there is a variety of nutritional guidelines and acceptable macronutrient distribution ranges (AMDR) in the literature for optimizing training [31–34]. Although the evidence most commonly supports a balanced approach to macronutrient intake [35], in real-world settings, marathon runners' diets vary greatly [36].

1.1 Aims

This thesis aims to:

1. Review the body of evidence on habitual high-fat (HF) vs habitual high-CHO (HC) diets and their effect on exercise performance, and
2. Review the evidence on the effects of MCT supplements on exercise performance.
3. Investigate the effect of MCT and CHO supplements on running performance.
4. Investigate the dietary habits, including macronutrient and energy intake, and CHO or fat-loading strategies of marathon runners.

1.2 Hypothesis

The hypotheses of this thesis include:

1. Endurance performance will differ significantly between athletes consuming either habitual HF or HC diets, with HC diets resulting in improved endurance performance, particularly when conducted at a high intensity (above 75% VO_2max).
2. The use of MCT alone will not improve exercise performance when compared to CHO. However, the combination of MCT and CHO will be more effective in improving performance compared to CHO alone.
3. The dietary habits of marathon runners will show a high dietary intake of CHO (> 60%), with a majority of runners opting to CHO-load on the days before an event. Habitual fat intake will be significantly lower than CHO intake, and few runners will choose to fat-load on the days before an event.

1.3 Thesis Structure

As is typical in research, this thesis evolved and adapted as new insights emerged, leading to a shift in focus. Originally, this study was designed to address Aims 1-3. Furthermore, aim 3 was designed to compare different diet interventions (HF vs high-CHO for 4 weeks) as well as the effects of MCT and CHO supplementation. However, eliciting the dietary interventions was not possible, and that aspect of the study was removed. This is discussed in Chapter 4 in more detail. Furthermore, during the experimental trial investigating Aim 3, it became evident that participants' habitual diets were not meeting recommendations for endurance performance. As a result, aim 4 was introduced to characterize the dietary habits of marathon runners and assess how closely they align with sports nutrition guidelines. To this end, this thesis is presented in six chapters as follows:

Chapter 2: Narrative Literature Review

Chapter 3: Medium-Chain Triglycerides in Exercise Performance: A Scoping Review of Cyclist Bias and the Need for Runner-Specific Research.

Chapter 4: An Investigation of Medium-Chain Triglycerides and Carbohydrates on Running Performance in a Randomized Cross-over Study.

Chapter 5: Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO and Fat-loading Strategies Used in Preparation for a Marathon.

Chapter 6: Final Conclusion

Chapter Two: Narrative Literature Review

This literature review first discusses how the body utilizes various energy substrates during exercise and how muscle fuel stores are mobilized to meet the demands of prolonged physical exertion. It subsequently examines the impact of high-CHO (HC) diets on exercise performance, considering the timing and amount of CHO intake before, during, and after exercise events. In addition, the concept of fat adaptation and its implications for exercise performance are discussed, with a focus on the effects of high-fat (HF) supplementation, including MCT, on energy metabolism and endurance. An important aspect of the review involves the gastrointestinal (GI) processes related to digestion, absorption, and gastric emptying of CHO, fats, and MCT, particularly how these processes influence nutrient availability and subsequent exercise performance.

Finally, this literature review aims to provide an understanding of how nutrition influences exercise performance, offering valuable insights for athletes, coaches, and researchers dedicated to enhancing athletic outcomes through tailored nutritional strategies.

2.1 Macronutrients

2.1.1 Carbohydrates

Carbohydrates are formed of carbon, oxygen, and hydrogen atoms and act as the primary energy source for skeletal muscles and the brain, and various other cell types, such as the liver and immune cells [8,15,37]. Chemically, they are classified into simple CHO and complex CHO.

The basic chemical unit of CHO is the monosaccharide, which is the simplest form of CHO [38,39]. The three most significant dietary monosaccharides are glucose, fructose, and galactose. Disaccharides consist of two monosaccharides linked together and include sucrose (glucose and fructose), maltose (two glucose molecules), and lactose (glucose and galactose). Simple CHO consists of small molecules naturally found in fruits and dairy products. Complex CHO contain three or more monosaccharides bonded together and are categorized into oligosaccharides and polysaccharides [38,39]. Oligosaccharides are composed of 3-10 monosaccharides. They are found in wheat products, oats, legumes, and whole grains. Human digestive enzymes do not break down oligosaccharides, so these CHO generally pass through the digestive tract without being absorbed. Polysaccharides, on the other hand, are made up of 11 or more monosaccharides. Starch, a digestible polysaccharide, consists of numerous glucose molecules linked in large, chain-like structures. Foods rich in starch include bread, pasta, rice,

and potatoes [39]. By understanding the different types and sources of CHO, we can better appreciate their roles in diet and exercise performance [8,15,37].

CHO undergoes digestion and is broken down into its simplest form, glucose, which is absorbed from the small intestine into the bloodstream. It first passes through the hepatic portal system and the liver before entering the muscle cells [39]. Blood glucose is readily available for glycolysis during exercise, while any excess is stored in the muscles and liver as glycogen for future energy demands. Digestion of CHO is further discussed in section 2.3.

CHO are the primary fuel source during high-intensity exercise, as it provides rapid energy directly to the muscle, from both blood glucose and liver and muscle glycogen stores. The use of CHO during exercise is further discussed in 2.2.1-2.2.1.4.

2.1.2 Fats

Fats, known as lipids, are a group of hydrophobic molecules composed mainly of carbon, hydrogen, and oxygen. The basic building blocks of fats are fatty acids and glycerol [1,39]. Fatty acids can be classified as saturated or unsaturated based on the double bonds in their hydrocarbon chains. Saturated fats have no double bonds, resulting in a straight structure that allows them to pack tightly together, making them solid at room temperature. Unsaturated fats contain one or more double bonds, introducing kinks in the chain that prevent tight packing, making them liquid at room temperature. Fats can also be categorized into triglycerides, phospholipids, and sterols, each serving different functions [1,39].

Fats are found in a variety of foods [40]. Saturated fats are typically present in animal products such as meat, dairy, and eggs, as well as in some plant oils like coconut and palm oil. Unsaturated fats are abundant in plant-based oils (such as olive, canola, and sunflower oil), as well as fatty fish such as salmon and mackerel. Unsaturated fats are essential for a balanced diet and provide numerous health benefits when consumed in appropriate amounts [40]. The digestion and absorption of fats are further discussed in section 2.3.

Fats are a crucial source of energy during endurance exercise, especially during prolonged, low to moderate-intensity activities [41–44]. While CHO are the preferred energy source for high-intensity efforts, the body increasingly relies on fat metabolism as exercise duration extends, and glycogen stores become depleted. The use of fats during exercise is further discussed in sections 2.2.2-2.2.2.4.

2.1.3 Proteins

Proteins are complex macromolecules of amino acids, which are organic compounds composed of carbon, hydrogen, oxygen, nitrogen, and sometimes sulphur [45]. The basic building blocks of proteins are 20 different amino acids, which are linked together by peptide bonds to form polypeptide chains. The sequence of amino acids determines its specific structure and function. Proteins can be classified based on their structure into primary, secondary, tertiary, and quaternary forms. The primary structure is the linear sequence of amino acids, while the secondary structure refers to local folding patterns such as alpha-helices and beta-sheets. The tertiary structure is the overall three-dimensional shape of a single polypeptide chain, and the quaternary structure involves the arrangement of multiple polypeptide chains into a functional protein complex [1,45].

Proteins are found in a wide variety of foods, with animal sources like meat, fish, eggs, and dairy products being particularly rich in complete proteins, which contain all essential amino acids [46]. Plant sources such as legumes, nuts, seeds, and grains also provide proteins, although they may lack one or more essential amino acids, making it important for those relying on plant-based diets to consume a variety of protein sources to meet their nutritional needs [46].

The digestion of proteins begins in the stomach, where the enzyme pepsin breaks down proteins into smaller polypeptides. This process continues in the small intestine with the aid of pancreatic enzymes like trypsin and chymotrypsin, which further degrade polypeptides into smaller peptides and individual amino acids. These amino acids are then absorbed through the intestinal lining into the bloodstream and transported to various cells in the body. Once inside the cells, amino acids are used to synthesize new proteins, which are essential for bodily functions, including tissue repair, enzyme production, and immune response [45,46].

In the context of endurance exercise, proteins play a role in both energy metabolism and muscle recovery. However, proteins provide very little energy during endurance training compared to fats and CHO, which are the primary sources of energy during prolonged exercise, with proteins contributing minimally [47,48]. During extended periods of exercise, some amino acids can be converted into glucose through gluconeogenesis, providing a supplementary energy source. Although their role in energy provision is minor, proteins are vital for repairing and rebuilding muscle tissues that undergo stress and micro-damage during endurance activities [47,48].

Consuming adequate protein in the hours before and after exercise helps to enhance muscle protein synthesis, reduce muscle soreness, and promote recovery, ensuring that athletes can maintain and improve their performance over time [47,49,50]. Due to the limited use of protein during endurance exercise, it will not be discussed in detail in this thesis.

2.1.4 Fuel Stores of Skeletal Muscle

Skeletal muscle acts as a storage site for both CHO and fats. CHO are stored as muscle glycogen in the sarcoplasm, typically ranging from 13-18 $g.kg^{-1}$ of wet weight (ww) [39]. An average runner or cyclist's thigh muscles contain approximately 300g of muscle glycogen. Additionally, around 100g of glycogen is stored in the liver, which is released in a post-absorptive state to maintain steady blood glucose concentrations [39]. The amount of glycogen stored is largely determined by the amount of CHO in a person's habitual diet [51], as a diet high in CHO will increase glycogen stores, whereas a low CHO diet will decrease stores [5,8,52,53]. The effects of diet on glycogen stores are further discussed in section 2.2.1.1.

Fats are stored as triacylglycerol in white adipose tissue. These molecules are broken down by lipase to release FFA into the circulation, making them available for muscle uptake during exercise. Studies on FFA indicate that muscles store approximately 12 $g.kg^{-1}$ww of triacylglycerol [39]. A diet high in fat can increase resting FFA concentrations, increasing fat usage during exercise, as discussed further in section 2.2.2.1.

2.1.5 The Energy Requirements of a Marathon

Covering the distance of a marathon (42.2 km) requires large amounts of energy to sustain running performance for many hours. The total number of calories required for an athlete is typically between 18-25 $KCal.min^{-1}$ [54], otherwise expressed as 1 $KCal.kg^{-1}.km^{-1}$ [55], thus translating to approximately 70 $KCal.km^{-1}$ for a 70 kg runner [56]. Pace (expressed as $km.hr^{-1}$) has little effect on running energy expenditure [56], and the total energy expenditure for a specific distance will not be significantly different if run at a faster or slower speed. When comparing two runners covering, for example, 10km, their energy expenditure would be the same even if runner A ran the distance at a faster pace than runner B.

Elite-level athletes can run an entire marathon at ~85% VO_2max, which is considered high-intensity exercise [54,56]. Although the body can metabolize both fats and CHO for energy, at high intensities, the body metabolizes predominantly blood glucose and glycogen (from both the liver and muscle), enabling a rapid fuel supply to the contracting muscles. At lower intensities,

the body uses a higher percentage of fat to supply a slower, longer-duration fuel. If CHO were the only fuel source during exercise, the body's supply of liver glycogen would deplete in the first 6-8 km and muscle glycogen in the next ~34 km [54,56]. These calculations are based on a 70 kg runner following a diet high in CHO (> 60% total intake) with approximately 120 g of liver glycogen and 600 g of muscle glycogen at the start of exercise [57–59]. Thus, this would equate to total depletion at 40 km if only CHO were used. However, using only one substrate is unlikely, and fats also contribute as fuel. Typically, glycogen depletion patterns during a marathon run at 70-80% VO_2max are ~0.3 $g.kg^{-1}.km^{-1}$. Once depletion occurs, the phenomenon known as "hitting the wall" is experienced. At this point, when muscle glycogen concentrations are below 3-5 $g.kg^{-1}$ of wet muscle, fatigue is reached and the runner has to reduce their pace substantially [54–56,60]. Fatigue is a progressive, multifactorial process characterised by a decline in the ability to generate force or, in the context of endurance exercise such as running or cycling, to sustain a given speed [61,62]. It may arise from central factors, including reduced neural drive or altered neurotransmitter function [61], and peripheral factors such as substrate depletion, metabolite accumulation, or thermoregulatory strain [62]. In the present thesis, the focus is specifically on the role of fuel supply in contributing to fatigue. Importantly, fatigue and exhaustion are not synonymous: fatigue develops gradually and may be at least partially reversible, whereas exhaustion represents the point of task failure, when the cumulative effects of fatigue prevent exercise from continuing [61,62].

2.1.6 Substrate Use and Caliber of the Athlete

There is growing evidence that the caliber of an athlete (such as training status, competition level, and metabolic capacity) mediates how individuals respond to dietary manipulations intended to affect performance [63]. Higher-level, well-trained endurance athletes often have greater mitochondrial density, improved substrate oxidation capacity, and more efficient fuel switching, which may attenuate or modify the effects seen in less-trained individuals. Recent work by Burke et al [63], emphasises that the caliber of the athlete significantly modulates the effects of nutritional/dietary manipulations on performance outcomes. In the Burke et al [63], data show that higher-caliber endurance athletes possess greater metabolic flexibility, more efficient substrate utilisation, and more robust physiological reserve. These characteristics mean that interventions (for example, altering carbohydrate or fat availability) often have different magnitudes of effect in elite vs. non-elite athletes. Burke et al [63], also note that many studies

use less well-trained or recreationally active subjects, and so effect sizes observed there may overestimate or misrepresent what occurs in elite performers. Thus, when interpreting the literature, it is important to consider athlete caliber as a moderator variable influencing both substrate use and performance outcomes.

2.2 Macronutrients and Exercise Performance

Endurance exercise, such as long-distance running, relies heavily on the body's ability to efficiently use macronutrients as fuel. CHO and fats are the most crucial for providing the necessary energy to sustain prolonged physical activity. Understanding how these macronutrients are metabolized and utilized during exercise is essential, as it enables the development of targeted nutritional strategies that optimize energy availability, delay fatigue, and ultimately improve performance and endurance.

In this chapter, the respective roles of CHO and fats in fuelling endurance exercise, and the strategies for macronutrient manipulation to enhance athletic performance will be explored.

2.2.1 Carbohydrates and Exercise Performance

2.2.1.1 Carbohydrate intake days before an event

Carbohydrates play a vital role in providing energy during exercise, as the predominant substrate used during high-intensity exercise [39]. Super-compensation or CHO-loading is used to increase glycogen stores to prepare for long-duration races, which has been proven successful since the late ’60s [41]. A fundamental study conducted in 1967 by Swedish researchers, Bergstrom, et al [64], investigated glycogen depletion patterns during extended periods of endurance exercise [64]. The study observed the systematic depletion of muscle glycogen during exercise conducted at 77% VO_2max, which became depleted in subjects who cycled until exhaustion. A subsequent study conducted exercise trials in cyclists who cycled until voluntary exhaustion between 70%-75% VO_2max. Once again, it was found that muscle glycogen depletion was closely associated with fatigue and time to exhaustion [65]. The study highlighted that lower initial glycogen concentrations were associated with a shorter time to exhaustion, emphasizing the importance of CHO availability for endurance performance [65]. Further research on glycogen concentration and exercise performance was conducted by manipulating the amount of CHO consumed before exercise by comparing a HC (> 70% daily intake from CHO) and a low-CHO (< 10% daily intake from CHO) diet for 3 days [9]. The study found that muscle glycogen concentration was the highest in the subjects who consumed a HC

diet compared to the low-CHO diet. Additionally, these participants cycled for significantly longer until reaching exhaustion [9].

Originally, CHO-loading strategies commenced 7 days before an event, where the first 3-4 days were spent in a CHO-depleted state achieved using extreme exercise and diet-induced depletion techniques. The protocol consisted of depletion achieved through high-intensity, long-duration exercise, followed by a period of low CHO intake. This would then be followed by 3-4 days of loading or super-compensation [66]. However, this was subsequently modified with evidence showing that trained athletes could achieve super-compensation of glycogen stores without prior depletion.[14]. Sherman, et al, found that extreme exercise-diet depletion was not needed by testing three different diet interventions following exercise depletion, where participants completed a 20.9km running trial. Diet interventions included: A = 3 days 15% CHO + 3 days 70% CHO, B = 3 days 50% + 3 days 70% CHO, and C = 6 days 50% CHO. The findings of the study showed no change in exercise performance in any of the trials, indicating that extreme exercise-diet depletion strategies were not needed. Continuing from this, Costill, et al [14] examined how trained athletes' muscle glycogen concentrations responded to high-CHO intake following strenuous exercise, observing that these athletes exhibited a rapid rate of muscle glycogen resynthesis due to higher glycogen synthase activity, which facilitates quicker glycogen storage in muscles. As a result, the findings showed that trained athletes do not require prolonged periods of glycogen depletion before CHO loading to maximize their glycogen stores. This research challenged the traditional approach of glycogen depletion followed by CHO loading, highlighting that trained individuals could effectively replenish muscle glycogen stores with adequate CHO intake alone [14]. CHO-loading strategies were therefore adapted to 3 days of super-compensation, without the depletion phase. Subsequent research then showed CHO-loading could increase glycogen stores by 94% (from 93-180 $g.kg^{-1}.ww^{-1}$) in only one day, with no further increase in concentrations when loading for a further two days [67]. In the study, endurance-trained athletes consumed $10g.kg^{-1}.day^{-1}$ CHO. Muscle biopsies taken on day one and day three resulted in similar glycogen concentrations, revealing that one day is sufficient in super-compensating muscle glycogen stores.

Current recommendations are to tailor-make CHO-loading strategies based on the runner or athlete's preference. Some runners may prefer to load two days before an event and to follow a normal habitual diet the day before, to avoid GI discomfort [41].

Various factors affect the efficacy of CHO-loading [1]. Gender considerations have been acknowledged, as much of the existing research has predominantly involved male participants, often under the assumption that findings can be generalized to females without directly investigating gender-specific responses. Despite this, it is seen that females often are unable to elicit the same levels of glycogen super-compensation [39]. The reason for this might not be physiological differences based on gender, however, as it is hypothesized that females have reduced CHO intake and restrictive dietary habits that are inadequate to load glycogen stores [41]. Additional research conducted on females shows glycogen storage is increased during the luteal phase when compared to the follicular phase [41], however, this is not the scope of this thesis.

Recommendations made on the amount of CHO needed during the CHO-loading phase are often catered to the distance of an event, as a shorter distance event would require less glycogen than longer ones. An event covering 21 km would require approximately 300-400g glycogen compared to a full marathon (42 km), which would require significantly more glycogen [12,68]. Notably, the amount of glycogen needed is affected by factors such as exercise intensity and feeding during exercise. The higher the intensity of exercise, the more rapidly glycogen will deplete, and feeding during exercise may slow down the depletion of liver glycogen, but not of muscle glycogen. All things considered, current recommendations for CHO-loading include ingesting 5-7 $g.kg^{-1}.day^{-1}$ for events covering 21 km or less, and 8-12 $g.kg^{-1}.day^{-1}$ CHO for longer events such as marathons and ultramarathons. CHO-loading should occur 1-3 days before an event [69], and should be catered to each athlete, depending on whether they can tolerate such high volumes before competing.

2.2.1.2 Carbohydrate intake before an event

The ingestion of CHO in the hours leading up to an event plays a critical role in optimizing performance. Following CHO loading, athletes should strategically manage their CHO intake in the immediate pre-race hours to sustain adequate blood glucose availability during the event [70,71].

A 2014 systematic review paper reviewed 20 studies conducted on pre-exercise CHO ingestion and documented the effects on performance [72]. The results indicated a generally positive response to CHO ingestion, with more than half of the studies reporting improved performance. These improvements included increased exercise time to exhaustion during running or cycling at 60-80% VO_2max, enhanced time-trial performance during 15–45-minute cycling sessions,

and better 5km run times. Participants consumed 45-100 g or 1-5 g.kg^{-1} CHO, one to four hours prior to exercise [72]. The studies where CHO was ingested between one and four hours before exercise enabled near-basal concentrations of plasma glucose and insulin immediately before exercise [72], compared to ingestions less than one hour before, which reported elevated plasma glucose and insulin concentrations (the importance of maintaining stable blood glucose concentrations is discussed in the next section – 2.2.1.3). Additionally, meals ingested less than 1 hour before exercise resulted in large reductions in plasma glucose concentrations once exercise began, known as reactive hypoglycaemia, which reduced exercise capacity [72]. Recommendations are to consume a HC meal two to four hours before exercise to avoid a rapid increase in blood glucose and insulin concentrations, followed by a subsequent drop at the onset of exercise [72]. This time frame also allows for the complete digestion and absorption of glucose to prepare for exercise [58].

Jeukendrup [13] provided recommendations to consume CHO in any form, such as a solid, gel, or liquid, immediately before exercise to avoid hypoglycaemia. However, in athletes who commonly experience symptoms of hypoglycaemia (such as dizziness, fatigue, or pallor), eating CHO should be avoided for at least 90 minutes before exercise to allow for digestion and absorption, and for blood glucose to return to baseline concentrations before exercise [13]. To further reduce gut discomfort, meals should be low in fat and fibre [73]. (Digestion and gut discomfort are further discussed in section 2.3).

The recommended amount of CHO to consume in the hours before an event varies from 1-4 g.kg^{-1}, hence a 60 kg runner would consume between 60 -240g CHO. However, higher amounts above 1 g.kg^{-1} often result in severe gut discomfort, as well as hypoglycaemia and subsequent reduction in exercise capacity [17,71,74]. Additionally, consuming a high-CHO meal less than one hour before exercise can reduce fat oxidation during exercise, reducing endurance capacity, and causing the onset of fatigue [17].

Under circumstances where muscle glycogen has not been super-compensated before an event, the pre-race meal should comprise CHO with a high glycaemic index (GI) [73]. The GI of a food is the effect it has on increasing blood glucose from 1-100. In theory, ingesting pure glucose would cause an immediate effect, increasing blood glucose concentrations rapidly. This is due to the rapid digestion of high GI CHO, which enters the bloodstream, increasing blood glucose concentrations, and allowing faster absorption into the muscle cells during exercise[75]. When comparing glucose to fructose response, fructose shows a flattened curve in glycaemic

response, and when fructose was added to foods compared to those that had added sucrose, the fructose food resulted once again in a lowered glycaemic response, and sucrose resulted in a higher glycaemic curve [39]. This means foods high in glucose and or sucrose have the highest effect on increasing blood glucose concentrations, making it available for metabolism during exercise [39,75]. Additionally, when comparing whole white and brown rice, or whole lentils, to their ground-up form (ground into flour), the whole forms resulted in flattened glycaemic curves. Recommendations are to include smoothies with blended CHO-rich ingredients to increase the GI of meals, ensuring quicker energy availability. Caution is given to athletes who commonly experience symptoms of hypoglycemia when consuming CHO before an event. If so, they should opt for lower GI foods to enable less of a glycemic response, avoiding a rapid glucose spike and subsequent drop [74].

In summary, pre-event meals should be consumed between two and four hours before an event, consisting of 1-4 $g.kg^{-1}$ of high GI CHO that are low in fat and fibre, avoiding any ingredients that illicit GI tract discomfort. However, most importantly, the amount of timing of CHO ingestion should be determined by the preference of the athlete [10,39,72,73,75,76].

2.2.1.3 Carbohydrate intake during performance

In the 1920s, a study conducted on six male runners before and after the Boston Marathon identified that severe hypoglycaemia was associated with exhaustion and poor performance [77]. The average plasma glucose concentration of the runners at the beginning of the race was 5.6 $mmol.L^{-1}$, which dropped to 2.5 $mmol.L^{-1}$ by the end of the marathon. A year later, the researchers advised the same six runners to eat high-CHO foods (such as candies) before and during the race [78]. The ingestion of candies during the race resulted in all six of the runners improving their running performance and finishing the race in faster times. Additionally, the authors noted that four of the runners were in poor physical condition in the 1924 race, and in excellent condition after the 1925 race, displaying no signs of hypoglycaemia, with plasma glucose concentrations between 4.5-6.3 $mmol.L^{-1}$ [78]. This suggests that maintaining relatively higher plasma glucose concentrations may be responsible for delaying fatigue and sustaining performance during prolonged exercise.[77].

Although stored glycogen can sustain exercise for approximately 90 minutes, depending on exercise intensity, feeding, and pre-exercise glycogen concentration (as discussed in section 2.2.1.1), maintaining steady blood glucose concentrations can maintain exercise performance in events ranging from above 3-4 hours [76]. The consumption of CHO during exercise enables

the maintenance of plasma glucose concentrations (typically between 4.5-5.5 mmol.L^{-1}), thus reducing glycogenesis of the liver, and sparing liver glycogen [72].

While pre-race CHO fuelling and in-race CHO ingestion can help sustain blood glucose concentrations and delay fatigue, they do not prevent muscle glycogen depletion. Muscle glycogen breakdown is primarily regulated by contraction-related signals and energy demand within the muscle, rather than by circulating blood glucose. At the onset of exercise, glycogenolytic enzymes are rapidly activated by factors such as calcium release and shifts in the muscle's energy balance. These signals ensure that glycogen continues to be used according to the work being done, so even when extra glucose is supplied from the blood, the muscle still draws on its own glycogen stores [79]. This was demonstrated in the work by Coyle, et al [80], who tested highly trained male cyclists who cycled at 70% VO_2max until exhaustion, while either fed CHO or nothing. The CHO solution was 10% glucose, which was ingested in 10-minute intervals (60 g.hr^{-1} total CHO). The CHO-fed group maintained steady plasma glucose concentrations, resulting in a longer time to exhaustion. Despite this, muscle glycogen concentrations were similarly low (as measured by muscle biopsy) when reaching exhaustion between the fed and unfed groups, indicating that the maintenance of blood glucose does not spare muscle glycogen [80].

Interestingly, the "no sparing" is a general outcome but not universal, and depends on factors such as exercise mode, intensity, fibre type, and timing [81]. Under some specific conditions (such as intermittent exercise, lower absolute intensities, or when exogenous CHO delivery is very high and muscle demand is lower), small sparing effects have been reported, and sparing may be more evident in specific fibre types. However, during relatively high-intensity, continuous running or cycling that relies heavily on intramuscular glycogen, the muscle's intracellular signalling will sustain glycogenolysis despite the presence of blood glucose [81].

The importance of carbohydrate ingestion during exercise is further supported by evidence of substrate reliance, as reflected in measurements of the respiratory exchange ratio (RER). RER is a method of determining the oxidation of CHO during exercise, which is estimated through indirect calorimetry and the gaseous exchange of VO_2 and VCO_2 [58]. The equation developed by Frayn, Peronnet & Massicotte [82,83] assumes that non-protein fuels (CHO and fat) are the main contributors to energy and that protein oxidation is either negligible or accounted for separately [82,83]. At rest, protein oxidation is minimal (~5% of total energy); however, during prolonged exercise, the contribution of protein may rise between ~2-10% total energy. During

exercise, an RER value of 1.0 estimates the body is oxidizing 100% CHO, while 0.7 reflects 100% fat oxidation. An RER of 0.8 typically suggests a mixed substrate usage, with approximately equal contributions from CHO and fats [58]. It should be noted that the above RER values do not account for protein oxidation, which may lead to a small over- or under-estimation of CHO and fat oxidation depending. As intensity increases, so does the RER, indicating increased CHO oxidation, diminishing the reliance on FFA. This is known as the Cross-over Concept – where fat metabolism decreases, and CHO increases [58]. The shift in substrate utilization results in the depletion of muscle glycogen during high intensities. O'Brien et al, had runners perform a treadmill marathon in either a "fast" (~73% VO_2max) or "slow" (~64% VO_2max) condition. Despite overnight fasting and no carbohydrate ingestion during exercise, the faster group displayed respiratory exchange ratios (RER) close to 0.99, indicating ~85–90% of energy derived from CHO, whereas the slower group had RER ~0.90 (~60–70% from carbohydrate). More recently, Hawley & Leckey [84] reviewed studies of prolonged, intense endurance exercise lasting up to about 3 hours and concluded that competitive endurance athletes train and race at intensities that are highly dependent on carbohydrate-based fuels for sustaining ATP production [84].

Beyond the importance of sustaining plasma glucose concentrations for contracting skeletal muscle, it is also critical for central nervous system (CNS) function during prolonged exercise. The brain relies almost entirely on glucose as its primary fuel at rest, and reductions in circulating glucose can impair cerebral glucose uptake, disrupt neurotransmitter synthesis, and contribute to the onset of fatigue [85,86]. Studies using glucose infusion demonstrate that adequate plasma glucose availability helps maintain central drive and reduces ratings of perceived exertion, even when muscle glycogen remains relatively preserved [87,88]. These findings support the concept that plasma glucose stability slows the progression of central fatigue during endurance performance.

The optimal time to consume CHO during exercise varies, and recommendations include ingestion at the start of exercise and continuously in 10-30-minute intervals [76], with less frequent feedings resulting in decreased performance [18]. More important than the timing of CHO feedings is the amount. As muscles utilize blood glucose at a rate of 1-1.3 $g.min^{-1}$ during the later stages of exercise, the recommendations are to ingest 60 $g.hr^{-1}$ during continuous exercise lasting 1-2.5 hours [18,89–92]. Higher amounts, ranging from 90-120 $g.hr^{-1}$ have been recommended for ultra-marathon distances lasting over four hours, but can cause severe gut

discomfort [92,93]. Feedings should prioritize achieving recommended amounts of CHO, spread out evenly throughout the race, whereas large amounts in short intervals are not advised [76].

In addition to eating or drinking CHO during exercise, studies have shown the effectiveness of using CHO mouthwashes in maintaining performance [94,95]. Studies conducted on cyclists and runners found that washing the mouth with a sweet glucose drink activated the reward centers of the brain, enabling athletes to maintain performance. This mechanism is thought to involve the taste receptors in the mouth, which influence neural pathways and increase central drive, enhancing exercise output. This method is particularly useful for high-intensity exercises and is most effective in fasted conditions, or when rinsing in 5-10-minute intervals [94,95].

2.2.1.4 Carbohydrate intake post-exercise

Muscle glycogen depletion varies depending on exercise duration and intensity, with larger depletion following very intense exercise. Fortunately, following intense exercise, muscle cells become more permeable to glucose and increase glycogen synthase activity [96]. To optimize glycogen restoration, it is recommended to consume 1.0-1.5 $g.kg^{-1}$ CHO within 30 minutes post-exercise, and then every 2 hours for up to 6 hours, opting for high-GI foods. Additionally, combining a smaller CHO intake (0.8 $g.kg^{-1}.hr^{-1}$) with protein (0.2-0.4 $g.kg^{-1}.hr^{-1}$) can be as effective as consuming 1.2 $g.kg^{-1}.hr^{-1}$ of CHO alone [96], as the addition of protein repairs the damage experienced by the muscles during high-intensity exercise [96]. For rapid glycogen replenishment, 1-1.2 $g.kg^{-1}.hr^{-1}$ of CHO should be consumed during the first 4 hours post-exercise [96].

2.2.1.5 Summary

To prepare for exercise, athletes should consume 8-12 $g.kg^{-1}.hr^{-1}$ CHO for 1-3 days before exercise to maximize glycogen stores in the liver and muscle. In the hours leading up to exercise, recommendations are 1-4 $g.kg^{-1}$ of CHO two to four hours beforehand to allow for metabolism and absorption, avoiding hypoglycaemia. The specific timing, amount, and type of CHO should be tailored to individual needs and preferences. Consuming CHO during exercise can sustain exercise performance by maintaining stable blood glucose concentrations and reducing liver glycogen depletion. Depending on the endurance event's length, 60-120 $g.hr^{-1}$ of CHO should be ingested. To rapidly replenish glycogen stores after exercise, 1-1.2 $g.kg^{-1}.hr^{-1}$ of CHO should be consumed within the first 4-6 hours after exercise. These guidelines ensure adequate glycogen storage and muscle recovery, promoting optimal performance and recovery.

2.2.2 Fats and Exercise Performance

Despite the success of CHO in improving exercise performance, the depletion of glycogen stores is unavoidable, and fatigue eventually sets in during long-duration exercise. To this end, the use of fat as an alternate, and/or additional fuel source has been investigated. Such an investigation commonly includes consuming a HF diet for days or weeks before exercise testing, which affects energy metabolism, potentially reducing the rate at which glycogen is depleted [97–99]. Chronic consumption of HF diets, meals, and supplements increases circulating FFA, subsequently increasing the reliance on fat oxidation during exercise. To the end, the manipulation of plasma FFA availability has been used to investigate the interplay between fat and CHO metabolism during endurance exercise [100,101]. Increasing plasma FFA availability through heparin infusion or lipid-heparin infusion protocols has consistently been shown to elevate fat oxidation and attenuate muscle glycogen utilization at a given exercise intensity [100,101]. This demonstrates a clear competition between lipid and CHO oxidation, supporting the concept of the glucose–fatty acid cycle [102]. Conversely, suppression of plasma FFA levels through nicotinic acid ingestion results in a compensatory increase in CHO oxidation and accelerated muscle glycogen depletion during exercise [103,104]. More recently, Leckey et al [105], conducted a randomized, double-blind, crossover study involving ten elite male cyclists who completed a 31 km TT following ingestion of either a ketone diester (1,3-butanediol acetoacetate diester) or a taste-matched placebo. The supplementation protocol elevated circulating BHB concentrations (>3 $mmol.L^{-1}$) while suppressing plasma FFA concentration, thereby allowing the investigators to assess performance when fat availability was attenuated. Blood samples were collected at mid-trial and immediately post-exercise to quantify FFA, glucose, and ketone concentrations, and performance was assessed by mean power output and completion time. Despite markedly elevated ketone concentrations, TT performance was impaired by approximately 2%, and plasma FFA concentrations were significantly lower in the ketone condition compared with placebo. These findings indicate that reducing circulating FFA availability through exogenous ketone ingestion can impair endurance capacity, suggesting that an adequate supply of plasma FFA is required to sustain energy production during prolonged exercise, particularly at submaximal intensities. However, evidence supporting a positive exercise performance benefit of HF diets, meals, and supplements varies. The impact often depends on the intensity and duration of exercise, as well as the metabolic adaptations of the individual [15,28,106–108].

When interpreting studies on HF diets, it is important to distinguish between the effects of increased fat intake itself and those of reduced CHO intake. Many of the reported adaptations, such as increased mitochondrial fat oxidation capacity, reduced muscle glycogen availability, and altered exercise intensity domains, are more directly related to the low CHO content of the diet rather than the high fat content alone [42]. In practice, most HF interventions are simultaneously low in CHO, making it difficult to isolate the independent contribution of each macronutrient. Therefore, the physiological outcomes attributed to HF diets should be interpreted in the context of CHO restriction as the primary driver of metabolic change. This will be discussed in the following sections.

2.2.2.1 High fat intake days and weeks before an event

As outlined in the previous section, CHO remains the predominant substrate during higher-intensity exercise due to its direct relationship with increases in RER and the crossover from fat metabolism. However, given the limited storage capacity of glycogen compared with the body's vast fat reserves, an efficient ability to oxidize fat becomes essential for sustaining energy availability during prolonged exercise. In this context, the ability to increase FFA oxidation during high-intensity efforts could theoretically help spare muscle glycogen and delay fatigue.

Marathon runners efficiently metabolize fats at higher intensities due to the nature of the sport and the customary long-duration training sessions required [41]. In addition to training, further adaptations in fat metabolism are possible when following a HF diet.

In 1863, English undertaker William Banting introduced a revolutionary diet for the time, which focused on HF and low CHO intake, leading to significant weight reduction [109]. Though initially popular among the public for weight control, it wasn't until the 1920s that athletes began to explore its potential for improving performance. By the 2000s, the ketogenic diet, a variation high in fat, moderate in protein, and low in CHO, gained traction as a dietary approach to help manage conditions like insulin resistance and diabetes [109]. Although drawing interest among exercise physiologists due to their potential to enhance fat metabolism, studies in endurance sports consistently demonstrated compromised performance and reduced exercise capacity when following a HF diet, especially during high-intensity efforts, where CHO is the primary fuel source [109].

Following a HF diet typically refers to a habitual diet of 5 days – 4 weeks of a diet in which 60-75% of daily calories are from fat [2,41,42,109]. Due to the high energy yield from fats, CHO

intake is greatly reduced, often below 10% of daily intake. Recommendations vary, but a common recommendation to best elicit the benefits of an HF diet includes keeping CHO intake below 25 grams per day [43]. This results in ketosis, a state where resting beta-hydroxybutyrate (BHB) concentrations rise above 4 $mmol.L^{-1}$ [110]. Ketosis increases fat metabolism during exercise, subsequently reducing the use of blood glucose, and liver and muscle glycogen [42,110].

The effects of following a HF diet on exercise performance vary, and there is evidence showing no change [26,111] and decreased exercise performance [110,112]. However, little evidence supports that a HF diet improves exercise performance. Heatherly, et al [111] and Prins, et al [26] observed no change in performance during maximal effort 5 km running time trials (TT) after following a HF diet for three and six weeks, respectively, compared to habitual HC diets. However, subsequent studies conducted at high intensities demonstrated decreased sprint performance after following a HF for 6 days [112], reduced running economy during steady state running at 70% VO_2max, and increased energy expenditure when running until exhaustion after following the diet for 4 weeks [110].

A 2021 systematic review by Cao, et al [113] reviewed 10 studies investigating HF diets and their effects on exercise performance. All the studies were randomized controlled trials involving trained athletes. The diet interventions lasted between 5 days and 12 weeks, and all included diets high in fat (> 60%) and low in CHO (< 10%). When comparing the results across all 10 studies, which were conducted on varying bouts of running and cycling exercise trials (including Wingate sprints, 5km TT, and running until exhaustion), the authors observed no significant differences in VO_2max, maximum HR, time till exhaustion, or RPE between the HF versus HC groups [113]. The only significant change found across all 10 studies was a notable increase in fat oxidation within 100% of the studies (fat oxidation of 0.2-0.6 $g.min^{-1}$ to 1.0-1.5 $g.min^{-1}$, in the HC vs HF groups, respectively) [114]. Despite this, no positive effect on exercise performance was seen in any of the studies reviewed [113].

Despite increased fat metabolism with HF diets, studies demonstrating performance benefits are scarce. This is possibly due to the downregulation of CHO metabolism [41]. Evidence shows HF diets reduce concentrations of the key enzyme pyruvate dehydrogenase, which catalyses glycolysis [41.] Thus, decreasing glycogenolysis during high-intensity exercise. [41]. In addition, a HF diet reduces muscle glycogen stores before exercise, due to low daily CHO intake. As discussed in previous sections, achieving high concentrations of liver and muscle glycogen before exercise extends exercise duration, reducing the rate of fatigue. However, HF diets

cannot maintain high concentrations of stored glycogen, reducing high-intensity exercise. To avoid this, research has been conducted on the effects of combining an HF diet with 1-3 days of CHO-loading [27].

A common misconception is that consuming CHO, such as during CHO-loading, might impair the ability to metabolize fats efficiently. However, this is not the case. Burke, et al [115] conducted research on 8 male cyclists following a HF or HC diet for 5 days. On day 6, all the participants were CHO-loaded to increase resting glycogen concentrations, followed by a HC meal one hour before exercise testing on day 7. Results show an increase in resting FFA and glycerol concentrations on day 5 in the HF diet group compared to the HC diet group; however, resting concentrations were all similar on day 7 following a day of CHO-loading and a HC meal. Additionally, fat oxidation remained high during exercise (> 1.0 $g.min^{-1}$) in the HF diet group, despite CHO-loading and a pre-race HC meal. Hence, the metabolic adaptations of following HF diet are not attenuated by CHO-loading or a HC meal [115].

Similarly, Lambert, et al [27] examined five trained male cyclists performing a 2-hour steady-state ride at 70% VO_2max, followed by a 20 km TT. Participants followed either a habitual HC or HF diet for 6 days. Both groups were then CHO-loaded before exercise testing (consuming 10 $g.kg^{-1}$ CHO for three days). Results showed increased fat oxidation and decreased CHO oxidation during exercise, improving TT performance in the HF group. This further demonstrates that acute CHO intake does not impact fat adaptation.

2.2.2.2 High-fat meals before exercise

Similar to previous findings, research on the effect of HF meals consumed immediately before exercise on performance has yielded inconsistent results. Some studies report no notable differences in performance between HF and HC meals consumed directly before exercise [116,117], while others observed improved performance [99]. Specifically, Okano, et al [117] did not observe any performance improvements within a group of trained cyclists when cycling at 65% VO_2max for 120 minutes, or in a subsequent cycle at 85% VO_2max until exhaustion, when ingesting a HF meal (60% fat, 30% CHO) compared to a HC (79% CHO, 10% fat) meal four hours before testing. Neither did Whitley, et al [116] during a 90-minute cycle at 70% VO_2max, followed by a 10km TT, when ingesting a HF vs HC meal an hour before exercise. However, both studies noted increased fat oxidation during exercise [99,117]. On the other hand, combining CHO-loading and pre-exercise HF meals has enhanced performance, as seen by Murakami, et al [99]. The study included all participants CHO-loading for three days, thereafter either

consuming a HC or a HF meal four hours before exercise testing. Participants within the HF group ran longer at ± 85% VO_2max until exhaustion, when compared to the HC group. These findings highlight that while HF meals alone can influence substrate utilization during exercise, the effect of these meals is further modulated by habitual HF intake on the days leading up to exercise testing. Additionally, they highlight the efficacy of using both macronutrients to enhance performance.

2.2.2.2 High-fat supplementation before and during exercise

Another approach to enhance fat utilization is through supplementation, such as with ketones, as mentioned in the chapter introduction or MCT. Ketone bodies, such as acetone, acetoacetic acid, and beta-hydroxybutyrate (BHB) are endogenous but can be ingested exogenously in different forms, including ketone salts or esters [22–24,118,119]. Commercially available ketone supplements typically consist of ketone salts, containing 8-12g BHB combined with sodium. On the other hand, ketone esters are known as (R)-3-hydroxybutyl (R)-3-hydroxybutyrate, which are salt-free and not commercially available. The ingestion of ketones in either form results in resting blood BHB concentrations between > 0.5 - < 4 mmol/L^{-1} in 15-45 minutes, subsequently providing an additional fuel source during exercise [23,120,121]. A systematic review by Margolis & O'Fallon [121] found heterogeneous outcomes across 10 eligible studies conducted on ketone salts and esters with respect to effect on endurance performance. Results were inconclusive, with three reporting positive, 10 reporting null, and three reporting negative effects of ketone supplementation on exercise performance. Similarly, in a meta-analysis by Valenzuela, et al[122] no significant effects on exercise performance (from sprints to events lasting up to ∼50 min) or on physiological responses were reported when reviewing 13 studies comparing ketone esters and salts to placebo conditions. However, Poffé, et al [24] demonstrated that ketone esters could enhance endurance performance in male participants who underwent a three-week endurance training program, with either a ketone ester or a control drink following each session. In this study, the ketone ester group demonstrated a 15% higher sustainable training load and better power output in the final 30 minutes of a two-hour cycle compared to the control group [24]. In contrast, a more recent meta-analysis of eight randomized control trials by Brooks, et al [120] concluded that ketones do not significantly improve endurance exercise performance during time to exhaustion or within TT, despite increasing BHB concentrations.

The use of ketone supplements was the focus of my Master's degree [123], which showed no improvements in cycling performance in a group of 45 recreational cyclists, when compared to CHO or placebo groups.

MCT consists of three saturated fatty acids, each with 6 to 12 carbon atoms bound to glycerol [58] and are significantly shorter than long-chain triglycerides (LCT), which consist of fatty acids with more than 12 carbon atoms. MCT are commercially available in products such as coconut or palm kernel oil and contain caprylic acid (C_8) and capric acid (C_{10}) [124]. MCT provide 8.4 $Kcal.g^{-1}$ of energy [125].

MCT digestion begins in the mouth with the enzyme lingual lipase, continuing in the stomach and intestine, where pancreatic lipase hydrolyses them into medium-chain fatty acids (MCFA) and monoglycerides. This process is faster and more efficient than LCT, which require emulsification and enzymatic breakdown by bile salts and lipases before absorption in the small intestine [29,58,124]. Additionally, LCT requires the carnitine shuttle to enter the muscle cell, and MCT does not. Furthermore, MCT is absorbed directly into the portal vein bound to albumin and rapidly delivered to the liver for rapid oxidation [29,58]. These characteristics enable the metabolic rate of MCT to match that of CHO, in both the liver and muscle mitochondria, making MCT the preferred choice for exercise performance, when compared to other fats [29]. Although high-intensity exercise typically relies on glycolysis for rapid ATP supply, the cellular entry rate of MCT offers an alternative fuel source for such activities [58]. This can be supported by the work of Nosaka, et al [30] which compared the efficacy of MCT and LCT in improving endurance performance in a group of trained university athletes. Participants ingested a meal high in MCT or LCT one hour before cycling for 40 minutes at 60% VO_2max, followed by cycling until exhaustion at 85% VO_2max. The time to exhaustion was prolonged in the MCT group, demonstrating the enhanced performance efficiency of MCT compared to LCT.

The impact of MCT supplements on endurance sports has been the subject of multiple research studies in both cycling and running [15,28,29,52,107,126–130]. However, the majority of the research has been conducted on cyclists, with very little evidence on runners [130]. To avoid redundancy, this is a short review of the literature on MCT, which is discussed in Chapters 3-5. Briefly, similar to the evidence available on HF diets, the evidence on the effectiveness of MCT in improving exercise performance varies. Studies conducted on MCT showed exercise performance improvements when cycling during high-intensity TT [28–30]. Notably, Van Zyl, et al [28] observed improved cycling performance and faster TT times in MCT groups compared to

CHO groups. Opposing this, several studies have shown a decrease in performance during TT [15,28,107,126,127,131,132]. Furthermore, the work of Jeukendrup, et al [131] suggested that GI discomfort from MCT ingestion is a hindering factor to exercise performance. Although ineffective when used alone, MCT supplementation shows enhanced effectiveness when paired with CHO. Work from Nosaka, et al [29] , showed the efficacy of combining MCT and CHO in extending exercise performance when cycling at 70% VO_2max until exhaustion, when compared to CHO alone [29]. Additionally, Van Zyl, et al [28], observed faster TT times during a 40 km TT when supplementing with MCT+CHO, compared to CHO alone.

To date, no research has been conducted comparing the effects of CHO and MCT supplementation when paired with a HF diet on exercise performance [130].

2.2.2.5 Summary

Research on the effect of HF diets, meals, and supplements on endurance exercise has had mixed outcomes. All HF strategies enhance fat oxidation but without subsequent improvements in exercise performance. Additionally, the evidence supports reduced CHO metabolism when eating a HF diet for weeks or days, or meals or supplements directly before or during exercise, which limits performance at high intensities.

HF supplements, such as MCT, offer a faster-metabolizing fat source, that may support moderate and high-intensity exercise; however, effective dosage and timing recommendations vary. Despite the increased fat oxidation observed, reaching a conclusive understanding of the effect on exercise performance remains challenging. This is likely due to the variability in study protocols, including differences in diet composition, duration of dietary interventions, exercise modalities, and intensities tested.

2.3 Gastric Emptying, Digestion, and Absorption

When consuming macronutrients before and during an event, it is important to consider the rate at which they leave the gut, are digested, and are absorbed into the bloodstream, where they can then be transported into muscle cells for fuel.

CHO digestion begins in the mouth, where salivary amylase breaks down polysaccharides into smaller oligosaccharides and maltose [58]. Once swallowed, the food bolus travels down the oesophagus and enters the stomach. The majority of CHO digestion and absorption occurs in the small intestine, where the pancreas secretes pancreatic amylase into the duodenum, breaking down polysaccharides into disaccharides such as maltose, lactose, and sucrose.

Disaccharides are broken down by the brush border enzymes into glucose, galactose, and fructose. These monosaccharides are transported into the bloodstream through GLUT2 transporters, where they enter the portal circulation and are carried to the liver. Once in the liver, they can be stored as glycogen or released into the bloodstream to maintain blood glucose concentrations [39,58]. Alternatively, glucose is transported to muscle cells through specialized glucose transporters, primarily facilitated by insulin. Insulin stimulates the translocation of GLUT4 transporters to the muscle cell membrane, allowing glucose to enter via facilitated diffusion. Inside the muscle cell, glucose is phosphorylated to glucose-1-phosphate, which is used to synthesize glycogen through the enzyme glycogen synthase. This glycogen is stored in muscle cells and serves as an energy reserve for physical activity [39,58].

Unlike CHO, fat digestion does not begin in the mouth to a significant extent. While a small amount of digestion is initiated by lingual lipase, most fat digestion occurs later in the GI tract. Upon reaching the stomach, gastric lipase contributes minimally to triglyceride breakdown. The major difference arises in the small intestine, where fats require emulsification by bile salts before enzymatic action can proceed. This emulsification creates micelles, which provide a larger surface area for pancreatic lipase to hydrolyse triglycerides into FFA and monoglycerides [39,58].

The absorption of fats and CHO differs significantly. Unlike CHO, which are absorbed directly into the portal vein, fats are re-esterified into triglycerides within intestinal cells and packaged into chylomicrons. These chylomicrons enter the lymphatic system before reaching the bloodstream, leading to a slower rate of availability compared to the rapid absorption and utilization of glucose. This delayed process affects the timing and contribution of fats as a fuel source during exercise [39,58], as discussed in the above sections. The key factor in MCT's potential lies in its distinct difference in its digestion and absorption process when compared to other fats.

Emptying of the gut is regulated by factors such as the type of food ingested, and it takes between one and four hours for the gut to empty. Hence pre-race meals are to be consumed up to three to four hours before, to ensure complete absorption and metabolization [72]. Factors affecting the rate of emptying include the smell, sight, and thought of food, as well as the volume, energy density, temperature, and osmolarity of a drink [39,72].

A significant factor affecting emptying is the osmolarity of a drink, which is closely related to the CHO content. The higher the amount of CHO in a drink, the higher the osmolarity, which

can slow down emptying. Studies suggest keeping a drink's osmolarity between 200 – 400 $mOsm.L^{-1}$, which is typical for most sports drinks [39]. The type of CHO plays a role in the rate of absorption and can be seen in studies comparing glucose and fructose ingestion [72]. When comparing this combination to isocaloric glucose only, the gastric emptying and absorption is more rapid when combining glucose + fructose [72]. Effects may be due to the difference in the transporters, with glucose (SLGT1) and fructose (GLUT5) being absorbed differently. The combination allows for multiple transport of CHO, allowing more CHO across the brush border membrane per minute. Research comparing the two showed higher oxidation rates in the combination of glucose + fructose (1.75 $g.min^{-1}$) versus isocaloric glucose (1.0 $g.min^{-1}$) [72].

Other factors to consider include exercising in hot temperatures, which can cause dehydration and slow gastric emptying [72]. Individual variability is another important consideration, as gastric emptying can differ significantly among individuals and genders, as women often have slower gastric emptying rates than men [72]. Finally, exercise intensity has a notable impact, as gastric emptying rates tend to decrease at intensities exceeding 80% of VO_2max [72]. The goal is to increase gastric emptying to a rate that facilitates fast absorption of substrates into the muscle to supply rapid energy during exercise [72].

Training the gut is a method of repeatedly exposing the GI tract to similar foods or supplements and thereby improving gastric emptying and absorption during endurance exercise [133]. The practice of gut training is nutrient-specific, and repetitive exposure to different macronutrients can elicit different results, e.g., training the gut with an HC diet can increase Sodium-Glucose Linked Transporter 1 (SGLT1) transporters in the intestines, resulting in increased CHO absorption and oxidation whilst exercising [133].

Additional factors concerning the gut during exercise are gut discomfort and stress, which are experienced in 30 – 50% of athletes [134]. The occurrence and severity of discomfort are highly individualized, and the causes are due to many factors, such as dietary intake of fibre, fat, and highly concentrated CHO drinks, which commonly elicit discomfort [134]. Notably, Jeukendrup, et al [135] investigated gut discomfort in a group of 29 triathletes. Of the participants, 93% experienced some form of GI tract discomfort, with 23% reporting severe complaints during an Ironman distance triathlon, where no new supplement protocol was used (only habitual diet and supplementation strategies were followed).

Although discomfort is reported in most endurance athletes, the most frequent reports are seen in runners [135], possibly due to the repetitive movements of the stomach during a race.

Prevention techniques include limiting fat, protein, and fibre up to 24 hours before a race and ensuring that CHO does not exceed a 10% concentration immediately before and during a race [96].

Furthermore, gut training can be used to reduce GI discomfort [136]. Costa, et al [137], investigated the effects of two weeks of gut training in 25 endurance runners. The participants consumed either 30g CHO in a gel disc, a CHO food, or a placebo during two hours of running at 60% VO_2max followed by a one-hour distance test (covering the most distance possible in the time given). The tests were conducted before and after two weeks of gut exposure, resulting in reduced GI stress and improved exercise performance in both the CHO-disc and CHO-food groups when compared to the placebo [137].

This adaptation was also seen in an investigation on MCT by Misell, et al [106], in a group of endurance runners who ingested 60g MCT for two weeks. Although gut discomfort was experienced in all the runners at first, two weeks of chronic ingestion resulted in reduced gut discomfort in the majority of the participants [106]. A recent review on MCT use recommended a daily intake of 50–100 grams, advising individuals to start with smaller amounts and gradually increase intake. Dividing the total across multiple meals was suggested as a strategy to improve GI tolerance [138].

2.4 Exercise modality: Running versus cycling

Exercise modality, such as running vs cycling, influences both the pattern of substrate utilisation and the prevalence and character of GI symptoms. These differences are mechanistically important when comparing studies of nutritional interventions (such as MCT) conducted in cyclists with studies performed in runners.

2.4.1 Substrate utilisation

A number of controlled comparisons report higher fat oxidation during running than cycling when exercise intensity is expressed as the same relative % VO_2max [139–141]. Achten, et al, [139] conducted a direct comparison of fat oxidation during running versus cycling in twelve moderately trained males (VO_2max ~66.9 ± 1.8 $mL.kg^{-1}.min^{-1}$). Subjects completed graded exercise tests on both modalities, with three-minute incremental stages until exhaustion. Measurements of VO_2, VCO_2, and HR were collected continuously, and fat oxidation was calculated by indirect calorimetry assuming non-protein fuel contributions. Their findings showed that while the relative intensity at which maximal fat oxidation occurred was similar

in running and cycling (~60-65% VO_2max), the magnitude of fat oxidation was substantially higher in running (0.65 $g \cdot min^{-1}$) compared with cycling (0.47 $g \cdot min^{-1}$). These results imply that at moderate to high submaximal intensities, running enables greater absolute fat oxidation [139,142].

Mechanisms that likely contribute to higher fat oxidation in running include differences not only in contraction patterns and muscle recruitment, but also in how perfusion and substrate delivery vary between modalities. For example, Cheneviere, et al [143] assessed thirteen moderately trained participants performing graded treadmill and cycle ergometer tests with three-minute incremental stages. They applied a sinusoidal model to the fat oxidation vs intensity curve and found that running exhibited greater "dilatation" (i.e. wider intensity range with appreciable fat oxidation) and a rightward asymmetry (peak fat oxidation shifted to somewhat higher intensities) compared to cycling [143].These methodological findings suggest that running uses more total muscle mass, greater engagement of postural and stabiliser muscles, and possibly increased intramuscular triglyceride utilization, in addition to differences in capillary perfusion and FFA delivery.

2.4.2 Gastrointestinal Function and Exercise Modality

Running and cycling show distinct GI symptom patterns and responses. Epidemiological and experimental data indicate that long-distance running is frequently associated with lower GI symptoms (urgency, diarrhoea, cramping), whereas cycling tends to produce both upper (nausea, reflux) and lower symptoms; triathletes show mixed patterns consistent with both modes [144].

Mechanisms underpinning these modality differences include mechanical impact from vertical oscillations in running, which increases mechanical stress on the intestines and may promote lower-GI symptoms [129,131]. Additionally, posture and intra-abdominal pressure play a role. Upright running changes abdominal configuration and may promote different mechanical stresses compared with the semi-recumbent/forward-leaning posture of cycling, which affects gastric emptying and reflux risk [145]. Furthermore, splanchnic blood flow redistribution affects GI symptoms, as exercise intensity induces splanchnic vasoconstriction; however, the absolute recovery may differ between running and cycling depending on thermoregulatory demand and the pattern of muscular work (which influences sympathetic outflow) [146,147,148].

2.5 Gender Difference in Substrate Metabolism

Sex-based differences in substrate metabolism during endurance exercise have been documented [149–151]. Women generally display a greater reliance on lipid oxidation and a reduced reliance on CHO metabolism at the same relative exercise intensity compared with men, partly due to differences in circulating oestrogen, which enhances lipolysis and mitochondrial fat oxidation [150]. This metabolic profile is associated with a slower rate of muscle glycogen depletion in women, contributing to sex-based variations in endurance performance responses [152].

Dietary manipulations may also produce differential effects between sexes. For example, women appear to derive less benefit from classical carbohydrate loading strategies, possibly because of lower glycogen synthase activity and hormonal influences that limit glycogen supercompensation [152]. This can be seen in the work by Tarnopolsky, et al [152], which investigated sex-based differences in glycogen storage and utilization following CHO loading. The study recruited six endurance-trained men and six endurance-trained women, all matched for aerobic fitness (mean $VO_2max \approx 60$ mL.kg^{-1}.min^{-1}), who performed a 6-day dietary and training protocol designed to induce glycogen supercompensation. The protocol consisted of a glycogen-depleting cycling bout followed by three days of high CHO feeding (75% of total energy from CHO) while maintaining low training volume. Muscle biopsies from the vastus lateralis were obtained before and after the loading phase to assess glycogen concentrations. Results showed that men increased muscle glycogen by ~41%, whereas women showed no significant change despite identical dietary intake relative to body mass. Plasma oestrogen and progesterone levels were measured and were proposed to influence substrate utilization and glycogen storage efficiency. The authors concluded that female athletes may exhibit blunted glycogen supercompensation due to hormonal modulation of glycogen synthase activity and preferential lipid oxidation.

Conversely, HF diets may elicit distinct responses in women, as seen by Devries, et al [151], who investigated the influence of sex on metabolic responses to short-term adaptation to a HF diet in trained endurance athletes. The study recruited 18 well-trained cyclists and triathletes (9 men and 9 women) who completed two four-day dietary interventions in a randomized crossover design: a HF, low CHO diet (HFLC; 70% fat, 15% protein, 15% CHO) and a high CHO diet (HCHO; 10% fat, 15% protein, 75% CHO). Each diet was followed by a 90-minute cycling bout at 65% VO_2peak, during which substrate oxidation was assessed via indirect calorimetry.

The results demonstrated a significant increase in fat oxidation and reduction in CHO oxidation following the HFLC diet in both sexes. However, the magnitude of adaptation was smaller in women, who continued to rely proportionally more on CHO oxidation than men under the same dietary conditions. The authors concluded that women may exhibit a ceiling effect in fat oxidation, limiting further adaptation to HF feeding compared with men, which may explain inconsistent ergogenic outcomes in studies of HF diets or supplements in female athletes [151].

2.6 Exercise Testing

Running performance can be determined in several ways, including protocols such as running time until exhaustion (TTE), completing a time trial (TT), incremental or ramp exercise tests, repeated sprint tests (RST), graded exercise tests, and tests that mimic race conditions (such as marathons) [153]. Test validity is assessed via the coefficient of variance (CV). The CV represents the typical error of the measurements expressed as a percentage of the mean, where a smaller percentage equates to less variation [153].

TTE is typically conducted at a certain intensity, such as 70% VO_2max, where participants are asked to run until exhaustion when they voluntarily stop the exercise test. These tests are easy to administer and are a good option for measuring the benefits of macronutrients on endurance performance. Similarly, incremental running tests are conducted until exhaustion but are completed at varying intensities. They are a good method for measuring maximal intensities, such as peak treadmill speed, as well as VO_2max and lactate threshold. However, the results don't necessarily translate to prolonged exercise performance [153].

On the other hand, during a TT, participants are asked to cover a particular distance, such as 10 km as quickly as possible. Alternatively, they are required to run for a certain amount of time, covering as much distance as possible [153]. These are self-paced, mimicking real-world performance. TT protocols commonly have a coefficient of variation (CV) of < 5%, however, including a familiarization run and using well-trained runners can reduce the CV to < 1% [153]. When comparing a TTE and TT, the TTE commonly has a higher CV than the TT [153].

Very high-intensity type performance can be tested using RST, where multiple sprints are covered with short recovery intervals [153]. These tests are not commonly used for endurance runners due to the nature of the sport.

Race condition testing is conducted under steady-state conditions where participants are asked to run at a given intensity for a particular duration, such as running at 70% VO_2max for two

hours. These tests mimic real-life steady-state performance and are useful in measuring running economy (oxygen uptake at a given speed: VO_2) and physiological responses to exercise, such as HR and substrate utilization.

When testing the effects of macronutrients on exercise performance, researchers often opt for a combination approach when designing a testing protocol [153,154]. Such testing often includes a TT or TTE, which is precluded by a race condition, steady-state run, or cycle (in cycling trials), such as a 90-minute run at 65% VO_2max followed by a 10km TT [153,154]. Using this protocol has proven to lower CV by 1-4.4% [153].

2.7 Assessing Dietary Intake

Dietary assessment is an important tool in nutrition research and making dietary recommendations. The three primary methods are diet records, 24-hour recalls, and quantified food frequency questionnaires (FFQ) [155]. Diet records involve participants recording all food and beverages consumed over several days, most commonly used as a 3-day food record, which records all food and drink over two weekdays and one weekend day [156,157]. Alternatively, 24-hour recalls require participants to report their intake from the last day [155,157]. FFQ collect information on the frequency of consuming specific foods over a longer period, such as a month [155]. Each method has its strengths and limitations, such as respondent burden, accuracy, and feasibility varying among them [156]. The choice of method depends on the research question, study design, sample characteristics, and size [155].

Food records are commonly used in diet intervention and performance studies [27,98,106,129,158]. Limitations include inaccurate reporting from the participants. A method used to reduce inaccuracies is the weighing of food as it is recorded, as used by Lambert, et al [27], when comparing habitual diets in a group of trained cyclists. Participants were asked to record their dietary intake for 3 days (two weekdays and 1 weekend) and weigh each food before recording [27].

To better understand habitual eating over a longer period, FFQs are used to track food intake over weeks or months [155–157]. These include many common food items (e.g., 124-line items). The use of FFQ explains typical portion sizes to enable accurate reporting. Despite FFQ being slightly more time-consuming, they give an accurate representation of food intake when compared to short-duration dietary records or recalls [155].

2.8 Chapter Summary

This chapter introduces the relationship between nutrition and endurance performance, focusing on how CHO and fats contribute to fuelling long-duration exercise. The predominant approach in sports nutrition has long favoured CHO intake before, during, and after exercise to maximize glycogen stores, sustain energy supply, and improve performance. This strategy is particularly well-supported for endurance events such as marathons, where CHO availability is crucial for delaying fatigue. However, due to the body's limited glycogen stores and the inevitable onset of depletion during prolonged exercise, there has been increasing interest in alternative fuelling strategies that aim to enhance fat utilization and prolong endurance capacity.

Research into HF dietary strategies has explored various approaches, including habitual HF diets, pre-exercise HF meals, and HF supplements, particularly MCT. The rationale is that increasing fat oxidation may help preserve glycogen stores and provide an additional energy source during prolonged exercise. However, despite an increase in fat metabolism with HF strategies, evidence supporting improved endurance performance remains inconsistent. While HF diets and meals have not been shown to outperform CHO-based strategies, some research suggests that combining CHO with MCT supplementation may enhance performance in certain conditions.

To address these gaps, this thesis conducted a scoping review to examine the effects of MCT on exercise performance. Additionally, an experimental trial was conducted on male and female endurance runners to evaluate the impact of MCT supplementation on running performance. Finally, an observational descriptive study explored marathon runners' dietary habits and pre-race nutritional strategies to provide insights into their current eating and supplementation habits. The evidence presented in this research aims to contribute to the ongoing debate on the most effective fuelling strategies for endurance exercise. The findings could help determine whether fat-based strategies are meaningful in endurance performance and, if so, under what conditions they may be beneficial.

Chapter Three: Medium-Chain Triglycerides in Exercise Performance: A Scoping Review of Cyclist Bias and the Need for Runner-Specific Research.

Chapter Introduction

The narrative literature review in Chapter 2 explored the role of CHO in enhancing endurance performance and examined the use of fat through long-term dietary intake or supplementation during exercise. However, few studies have demonstrated positive performance outcomes from HF diets, with most findings indicating a reduction in exercise capacity, particularly at high intensities. The use of HF supplements, such as MCT, shows the potential to enhance performance due to their rapid absorption, which mimics that of CHO. The following chapter aims to provide a further understanding of the body of research conducted on MCT and exercise performance.

Abstract

This scoping review explored the current evidence on the effects of MCT on endurance performance. **Methods:** The review was conducted following the PRISMA extension for Scoping Review using several databases. Nine randomized controlled trials involving endurance-trained runners and cyclists who ingested MCT before or during exercise were included. **Results:** A notable aspect of the scoping review was the limited number of studies conducted on running performance, with only two to date. Additionally, the effects have not been investigated in female endurance athletes. Despite MCT's promising metabolic properties such as rapid oxidation and potential for enhanced fat utilization during exercise, the results did not demonstrate significant improvements in exercise performance in the majority of the studies. GI discomfort associated with MCT supplementation was also noted, raising concerns about dosage. However, the combined use of MCT and CHO demonstrated positive results in two studies. **Conclusions:** This scarcity of research on MCT and running performance underscores the need for further investigations. Additionally, the review revealed variations in study methodologies, including differences in MCT dosage, duration of supplementation, and timing of administration relative to exercise. These discrepancies contribute to the challenge of drawing conclusive findings regarding the effectiveness of MCT for endurance performance, particularly in running. Future research should aim to address these methodological discrepancies and explore optimal supplementation strategies.

Keywords: Medium chain triglycerides (MCT), Running performance, Endurance performance, Fat oxidation, Glycogen sparing.

3.1 Introduction

Endurance sports necessitate strategic dietary considerations for daily nutrition and in-race fuelling, with a particular emphasis on macronutrient intake, particularly CHO and fats [57]. As described in the previous chapter, CHO are metabolized to glucose during digestion and stored as liver or muscle glycogen, serving as the primary energy source for muscles during exercise [57,96]. Increasing CHO intake is a well-established, evidence-based strategy for optimizing performance [131,159]. On the days preceding an event, CHO-loading techniques significantly increase muscle glycogen stores and delay fatigue [28,44,160,161]. CHO feeding during exercise maintains plasma glucose concentrations and enhances exercise performance [28,131]. Despite effective CHO loading, the depletion of muscle glycogen during prolonged exercise remains a primary cause of fatigue [11]. To address this, strategies have focused on sparing muscle glycogen through dietary manipulation, such as supplementing with lipids [5,6,42,162–166], akin to MCT [107].

The rapid absorption rates of MCT suggest a rationale for using it to enhance endurance performance [107,131]. Indeed, studies show that incorporating MCT into one's diet may have positive effects on exercise performance [28–30]. This is attributable to the unique metabolic properties of MCT, which enable its rapid absorption into the muscle and liver mitochondria, as discussed in section 2.2.2.2. The rapid absorption of MCT enables them to serve as an alternative fuel source to glucose, which may reduce reliance on muscle glycogen for energy.

Several studies have investigated the use of MCT on cycling performance [20,28–30,52,126,131,142,167], but the results are inconsistent. The outcomes range from no change in cycling performance [52,126,167], to slower TT times [168], even when exercising at moderate to high intensities (55–100% of maximal effort). Specifically, MCT use has improved time-trial times [28] and increased time to exhaustion whilst cycling at 50-80% VO_2max [29,30]. However, gut discomfort is often reported [15,28,107,132].

The majority of the MCT research has been conducted on cyclists, with only two studies to date conducted on runners [129,132]. Although running and cycling may be similar, they possess different physiological and metabolic responses, such as the oxidation of fats and CHO during exercise [140]. Specifically, running has higher fat oxidation rates at the same relative intensity [140]. This metabolic distinction could derive specific benefits from MCT supplementation, due to runners utilizing the substrate more efficiently. Thus, MCT might not elicit performance benefits in cyclists, but they may in runners.

Numerous MCT supplements are currently available on the market, often promoted to athletes and recreational sports enthusiasts for enhancing energy availability and sports performance [132]. However, the existing research on MCTs is limited and presents various inconsistencies regarding their effects on exercise performance, optimal dosage, and timing. This scoping review aims to examine the current evidence on the effects of MCT on endurance performance. The review will explore potential benefits, as well as negative effects or limitations of MCT supplementation.

3.1.1 Rational

The existing body of literature on MCT use during exercise predominantly focuses on cyclists, with limited research conducted on runners. Moreover, the available studies present inconsistent findings, and the positive effects of MCT supplementation remain uncertain. Given the unique metabolic demands of running and the potential for MCT to enhance performance through increased fat oxidation and glycogen sparing, there is a clear rationale for investigating MCT use in runners. This scoping review aims to address the existing knowledge gap by examining the effects of MCT supplementation on exercise performance, with a focus on comparing its impact on running versus cycling. The objectives are to systematically map the current body of research on MCT supplementation concerning exercise performance, identify and analyse any performance differences associated with MCT use in cycling and running, and highlight knowledge gaps in the current literature, thereby informing potential directions for future research on MCT and exercise performance.

3.2 Materials and Methods

The search strategy followed Arksey and O'Malley's 5-step framework for scoping reviews, which involved: (1) identifying the research question, (2) identifying relevant scholarly articles, (3) study selection and screening, (4) charting the data and, (5) collating, summarizing, and reporting findings. All available papers published in English, across databases, reference lists of relevant studies, and key authors were searched to ensure the inclusion of the latest published papers relevant to the research question with the latest search date being 16 December 2024. The databases included PubMed, Cochrane Library, Medline, SportDiscus, Google Scholar, Ebsco, and Web of Science with no limitations placed on publication date. Additionally, a reverse Google Scholar search was conducted by examining the articles cited within this review to identify prior studies that contributed to its findings. We followed the PRISMA-ScR guidelines and checklist, which can be found online (https://osf.io/h8356/). The detailed search

strategy for databases included three concepts used to structure the search, including medium chain triglycerides, running (example keywords: endurance runners, marathon runners, long-distance runners, running, runners), cycling (example keywords: endurance cycling, cycling, cyclists) and performance outcomes (example keywords: exercise performance, running performance, running time, running economy, cycling performance, cycling time, cycling economy). Different combinations of these search terms were used in the various search databases to identify relevant articles. The study identification and data extraction processes were conducted by a single reviewer. This included screening titles and abstracts, reviewing full texts, and extracting data from selected studies. While this streamlined the review process, the involvement of only one reviewer presents a potential limitation, as it may increase the risk of missed studies or inaccuracies. To mitigate these risks, meticulous attention to detail was maintained throughout the process, and extracted data were cross-checked for consistency.

Lastly, elicit (elicit.org, accessed on 16 December 2024), a A.I (Artificial Intelligence) tool developed to synthesize the findings of research questions was also used to identify further articles to be included in the review. This process yielded 360 articles, as seen in Figure 1.

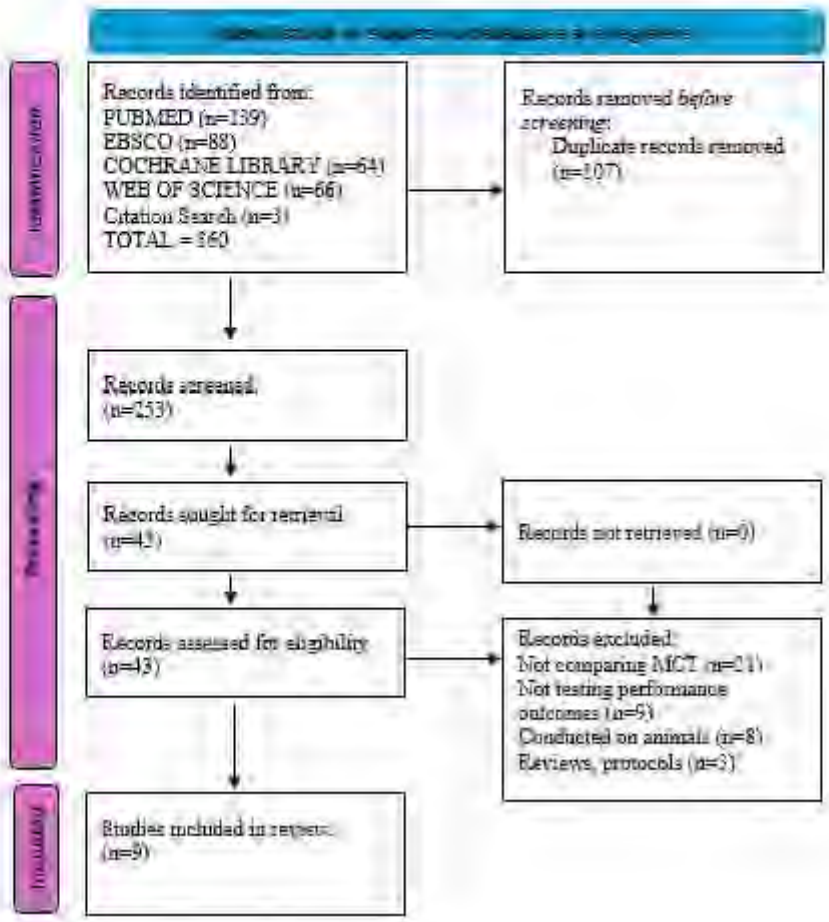


Figure 1. PRISMA diagram of scoping selection.

3.3.1 Eligibility

Studies were included if they were peer-reviewed journal papers, written in English, involving human participants, and original experimental trials, published at any time. The included studies reported: 1) the use of MCT, 2) participants as endurance runners or cyclists, and 3) performance outcomes, including time-trial times, oxygen uptake, and blood analyses (such as glucose, lactate, triglycerides, and BHB). No abstracts or reviews were included in this review. Abstracts provide only a summary of a study and lack detailed information to assess the quality and application of the research. Reviews do not present original research and including this could result in an inaccurate representation of existing research.

3.3 Results

The initial search yielded 360 articles from the databases (as seen in Figure 1). After removing the duplicates, reviews, study protocols, abstracts, and articles not in English, 43 full-text articles were evaluated for eligibility, studies were removed due to 1) other interventions used,

e.g.: ketones, 2) the participants were not endurance athletes e.g.: healthy adults, or active individuals 3) no exercise performance outcomes were measured, and 4) a non-human, e.g.: an animal study was conducted. Thus, nine papers met the inclusion criteria of this scoping review, as shown in Table 1.

3.3.1 Study characteristics

The studies' characteristics are shown in Table 1. While this results section includes a discussion of studies conducted on cyclists to provide a comprehensive overview of the evidence on MCT supplementation and exercise performance, the primary focus is placed on studies involving runners, as the main emphasis of this thesis is on endurance running.

All the studies were randomized, crossover designs, published between 1995-2005. The included studies comprised a total of 72 male participants: 45 cyclists, 8 triathletes, and 19 runners. Based on the descriptions provided in the original studies, 48 were classified as endurance-trained athletes and 8 as elite-level athletes. Classification was not reported for 16 participants. The interventions of MCT included both chronic (seven – 14 days) and acute use of MCT, either on the day or hour before or during exercise testing.

3.3.2 Study Interventions

The interventions used included running or cycling at intensities ranging from 50-65% and > 80% VO_2max. Protocols included steady-state running and cycling lasting between 30-180 minutes, followed by TTs ranging from 40 km to 100 km; or running or cycling until exhaustion.

3.3.3 Supplementation and Diet

The running studies' MCT supplementation doses ranged from 34g for seven days [129] to 60g for 14 days [132], as seen in Table 2. The studies compared MCT to long-chain triglycerides (LCT) [129], or a placebo [132]. All participants followed a low-fat diet (< 30%) before and throughout testing. CHO and protein intake ranged from 50-60% and 12-15%, respectively. Of the seven cycling studies, none used chronic supplementation, with the majority of the studies ingesting MCT before (n = 4) [28,126,168,169] and during (n = 5) [28,126,131,168,169] exercise testing in 10-20 minute intervals. MCT dosage of the cycling studies ranged from 25-85 g, or 1.7-4.3% per bolus. All of the cycling studies compared MCT to CHO as well as the combination of MCT+CHO. Particularly two studies conducted by Jeukendrup, et al [15,131], contained largely

different amounts of MCT from the 1995 (29g) to the 1998 (85g) study. None of the cycling studies adhered to any particular diet leading up to the experimental trials.

Table 1. Methodologies and Study Designs of Eligible Studies

Reference	Study Design	Subjects	Exercise Testing	Outcomes Measure
Oopik, et al (2001)	Double-blind, cross-over, randomized, placebo-controlled.	7 Endurance Runners (males).	Running until exhaustion (80-85%).	Running Time to Exhaustion; Biochemical analysis.
Misell, et al (2001)	Double-blind, cross-over, randomized.	12 Endurance Runners (males).	30-minute run (85%) + running until exhaustion (75%).	Gaseous exchange; Running Time to Exhaustion; Blood analyses.
Jeukendrup, et al (1995)	Double-blind, cross-over, randomized	8 Triathletes (males).	180 minutes of cycling (57%)	Gaseous exchange, substrate utilization, Blood analyses.
Van Zyl, et al (1996)	Cross-over, randomized.	6 Endurance cyclists (males).	2-hour cycle (60%) + 40km TT	Substrate utilization; Blood analyses. Average cycling speed; TT times.
Jeukendrup, et al (1998)	Cross-over, randomized.	7 Endurance cyclists (males).	2-hour cycle (60%) + 15-minute TT (75%).	HR; RER; Substrate utilization; Blood analyses. Average work rate; TT times.
Goedecke, et al (1999)	Cross-over, randomized.	9 Endurance Cyclists (males).	2-hour cycle (55%) + 40km TT.	RER; Substrate utilization; Blood analyses. Average cycling speed.
Angus, et al (2000)	Cross-over, randomized.	8 Elite Cyclists (males).	100km TT	VO_2; HR; RER; Substrate utilization; Blood analyses. TT Times.
Horowitz, et al (2000)	Cross-over, randomized.	7 Endurance cyclists (males).	30-minute cycle (85%)	VO_2; HR; RER; Substrate utilization; Biochemical analysis.
Goedecke, et al (2005)	Randomized, placebo-controlled cross-over study.	8 Ultra-endurance Cyclists (males).	270-minute cycle (50%) + 40km TT.	RER; Substrate utilization; Blood analyses. Average cycling speed

**The percentages given are a % of maximal effort (ie: % VO_2max); HR = heart rate; TT = time trials = RER = respiratory exchange ratio; VO_2 = oxygen consumption.*

Table 2. MCT Dosage and Timing.

Reference	MCT Dosage	MCT Timing	Dietary Intervention
Oopik, et al (2001)	MCT (34g) or placebo.	Daily ingestion for 7 days.	A low-fat diet was followed throughout the trial.
Misell, et al (2001)	MCT oil (60g); or (LCT) (56g).	Daily ingestion for 14 days.	A low-fat diet was followed throughout the trial.
Jeukendrup, et al (1995)	CHO (214g); or MCT+CHO (149g+29g); (HCHO+MCT) or MCT.	4ml.kg^{-1} before exercise. 2ml.kg^{-1} in 20-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.
Van Zyl, et al (1996)	MCT+CHO (4.3%+10%); or MCT (4.3%); or CHO (10%).	400ml before exercise. 100ml during exercise in 10-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.
Jeukendrup, et al (1998)	MCT+CHO (170g+85g); or MCT (85g); or CHO (170g); or water.	8ml.kg^{-1} during warm-up 2ml.kg^{-1} during exercise in 15-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.
Goedecke, et al (1999)	MCT (32g); or CHO (72g) MCT+CHO (1.7%+10%); or MCT+CHO (3.44%+10%)	Before exercise. 400ml during exercise in 10-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.
Angus, et al (2000)	MCT+CHO (4.2%+6%); or CHO (6%); or placebo.	During exercise in 15-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.
Horowitz, et al (2000)	MCT+CHO (25g+0.72g.kg^{-1}); or CHO (0. 72g.kg^{-1})	Consumed 1 hour before exercise.	No diet intervention was used, and participants continued with their normal diet between testing.

Goedecke, et al (2005)	MCT (32g); or CHO (75g). MCT+CHO; (4.3%+10%); or CHO (10%).	Before exercise. 200ml during exercise in 20-minute intervals.	No diet intervention was used, and participants continued with their normal diet between testing.

3.3.4 Blood Analyses

Metabolic concentrations of plasma glucose, lactate, glycerol, FFA and BHB within the reviewed studies are summarised in Table 3. Oopik, et al [129], reported increased beta-hydroxybutyric acid (BHB) concentrations post-exercise in an MCT group when compared to a placebo group (1.029 ± 0.67 mmol.L^{-1} vs 0.369 ± 0.19 mmol.L^{-1}) after running > 80% VO_2max. Conversely, Missel, et al [132] observed no difference in BHB concentrations between MCT and LCT groups when running > 75% VO_2max. Six [15,28,126,131,169] of the cycling studies observed an increase in BHB concentration during exercise (ranging between 0.8-1.7 mmol.L^{-1}) in the groups containing MCT compared to those without (CHO or placebo groups, which remained below 0.5 mmol.L^{-1}). Similarly, FFA concentrations were increased with exercise in the groups containing MCT and CHO [15,28,52,131], particularly in the first 30 minutes of exercise.

Glycerol concentrations increased gradually during exercise in four of the studies reviewed, [15,106,129,131] but remained the same across groups. However, three studies [15,28,129]observed that the highest glycerol concentrations occurred when MCT was ingested compared to all other groups, reaching concentrations between 0.13-0.29 mmol.L^{-1}.

Despite no differences observed in plasma blood glucose concentrations between groups in the running studies, a number of the cycling studies showed a significant difference in plasma glucose concentrations in the groups containing MCT+CHO compared to other groups [15,28,52,126,131]. In these studies, plasma glucose concentrations were higher in the MCT+CHO groups compared to the MCT or placebo groups. Whilst the MCT+CHO groups were able to maintain euglycemic plasma concentrations, the MCT groups declined below 3.9 mmol.L^{-1} [15,28,52,126,131], specifically, in the 1995 Jeukendrup, et al [15] study where plasma glucose decreased below 3.5 mmol.L^{-1} after 180 minutes of steady-state cycling at 57% VO_2max after ingesting MCT [15].

Table 3. Blood Analyses

	Glucose	Glycerol	BHB	FFA	Lactate
Oopik et al (2001)	No difference between groups.	Increased in both groups, the greatest increase in the MCT group.	Increased in both groups, the greatest increase in the MCT group.	Not measured.	No difference between groups.
Misell, et al (2001)	No difference between groups.	Increased with exercise, no difference between groups.	Increased with exercise, no difference between groups.	No difference between groups.	No difference between groups.
Jeukendrup, et al (1995)	Gradual decline in the MCT group. Euglycemia in the MCT+CHO groups.	Increased in all the groups, the greatest increase in the MCT group.	Increased in the MCT group.	Increased in the MCT , HCHO+MCT and MCT+CHO groups.	No difference between groups during steady state. Increase in the MCT group at the end of the TT.
Van Zyl, et al (1996)	Increased in the CHO and MCT+CHO groups.	Increased in the MCT+CHO and MCT groups.	Increased in the MCT group.	Increased in the MCT and MCT+CHO groups.	Lowest concentrations in the MCT group compared to the CHO and MCT+CHO groups.
Jeukendrup, et al (1998)	Decreased in the MCT and PLA groups.	Increased in all the groups, the greatest increase in the MCT group	Increased in the MCT and MCT+CHO groups.	Increased in the MCT and MCT+CHO groups.	No differences between groups during steady state. Lowest concentrations in the MCT group.
Goedecke, et al (1999)	No difference between groups.	No difference between groups.	Increased in the MCT and MCT+CHO groups.	Increased in the MCT and MCT+CHO groups.	No difference between groups.

Angus, et al (2000)	Increased in the CHO and MCT+CHO groups.	Not measured.	Not measured.	Increased in all the groups, the greatest increase in the MCT+CHO group.	No difference between groups.
Horowitz, et al (2000)	Increase in the MCT+CHO group.	No difference between groups.	Increase in MCT+CHO group.	Not measured.	
Goedecke, et al (2005)	Not measured.	Not measured.	Not measured.	Not measured.	Not measured.

**BHB = beta-hydroxybutyrate; FFA = free fatty acids.*

3.3.5 Gaseous Exchange and Substrate Utilization

Misell, et al [132] observed an increase in respiratory exchange ratio (RER) in the MCT group in their study compared to the LCT group when running at 85% VO_2max (0.98 vs 0.90), but RER values were similar for both groups when running at 75% VO_2max [132]. Oopik, et al [129], did not measure gaseous exchange. Most of the cycling studies showed no significant difference in the rates of CHO and fat oxidation between groups. Specifically, Angus, et al [52], reported no differences in total fat oxidation during the TT when subjects ingested MCT+CHO compared with CHO. Similarly, neither did Goedecke, et al [169] when comparing fat and CHO oxidation during steady-state exercise between groups consuming MCT or CHO. However, the study by Van Zyl, et al [28], which observed a decrease in CHO oxidation in the MCT (9 ± 1 mmol.min^{-1}) and MCT+CHO groups (10 ± 1 mmol.min^{-1}), when compared to the CHO group (14 ± 1 mmol.min^{-1}). On the other hand, the 1995 study by Jeukendrup, et al [15] observed increased fat oxidation in both MCT and MCT+CHO groups, with the highest fat oxidation in the MCT+CHO group [15]. Additionally, the authors measured MCT oxidation via indirect calorimetry and stable isotope measures. Notably, they observed increased MCT oxidation in the MCT-CHO (6.6 ± 0.5 g.min^{-1}) group compared to the MCT group (3.1 ± 0.5 g.min^{-1}) during the last hour of the two-hour cycling test at 60% VO_2max [15].

3.3.5 Gastrointestinal Discomfort

GI discomfort was experienced in seven of the eight trials, as seen in Table 4. All 12 participants in the Misell study [132] experienced gut discomfort, reporting diarrhoea, nausea, or bloating. Five participants in the Oopik study experienced discomfort [129], with two reporting no discomfort. Symptoms were similar amongst the cycling studies, most commonly more severe in the MCT trials, with four cycling studies reporting discomfort. The most commonly experienced side effects in the cycling studies were vomiting, diarrhoea, cramping, and nausea [52,131,168,169]. Not surprisingly, gut discomfort was not noted when supplementing with 29g of MCT [15] . Severe discomfort was reported when supplementing with 85g of MCT [131]. However, the study by Van Zyl, et al [28], supplemented a total of 85 g of MCT during the exercise trials over three hours, whereas Jeukendrup, et al [131] provided the same amount over just two hours of exercise. Gut discomfort was prevalent in the Jeukendrup, et al [131] study, but not in the study by Van Zyl, et al [28].

3.3.6 Performance Outcomes

Key findings and performance outcomes are summarized in Table 4. In the study by Oopik, et al [129] no significant difference in time to exhaustion was observed when comparing the MCT and placebo groups. Similarly, Misell, et al [132] found no significant difference in endurance time between the MCT and LCT groups. The only study to observe significantly faster TT performance in the MCT+CHO groups compared to the CHO or MCT groups was the study by Van Zyl, et al [28] in which participants completed a 40km TT (MCT+CHO = 65.1 ± 0.5 min; CHO = 66.8 ± 0.4 min; MCT = 72.1 ± 0.6 min. $P < 0.05$). Although Jeukendrup, et al [15], found the fastest times in the MCT+CHO group, and the slowest times were seen in the MCT group during a 15-minute TT cycle after cycling at 60% VO_2max for two hours. Similarly, two other studies reported the slowest times in the MCT groups compared to the CHO or placebo groups during a 40km [168] and 100km TT [52].

Table 4. Exercise Performance and GI Tract Discomfort.

Reference	Exercise performance.	GI Tract Discomfort
Oopik, et al (2001).	No significant difference between groups.	GI discomfort was experienced in 5 of the participants.
Misell, et al (2001)	No significant difference between groups.	All participants reported symptoms, which were reduced with chronic consumption.
Jeukendrup, et al (1998)	No significant difference between groups.	Not reported.
Van Zyl, et al (1996)	TT times were fastest in the MCT+CHO group & slowest in the MCT group.	None reported.
Jeukendrup, et al (1998)	TT times were fastest in the MCT+CHO group & slowest in the MCT group.	2 participants vomited, 3 experienced diarrhea.
Goedecke, et al (1999)	No significant difference between groups.	1 participant vomited with LOW-dose and 1 participant experienced diarrhea, cramping, and nausea with HIGH-dose.
Angus, et al (2000)	TT times were slower in the MCT group compared to the CHO group.	4 participants reported GI symptoms, 2/4 severe symptoms: vomiting and diarrhea.
Horowitz, et al (2000)	No significant difference between groups.	GI symptoms were present.
Goedecke, et al (2005)	TT times were slower in the MCT group compared to the CHO group.	4 participants reported GI symptoms of vomiting, cramps, diarrhea and bloating.

3.4 Discussion

A notable finding of this review was the disproportionately small number of studies examining MCT use and exercise performance in runners, with only two studies identified. In addition of all the randomized controlled trials involving male endurance-trained runners and cyclists, none showed improved performance in MCT groups. Despite no performance benefits of MCT alone, the combination of MCT and CHO significantly improved TT performance compared to MCT or CHO in one of the studies [28,131].

The scarcity of runner-specific evidence is supported by similar reviews [130,170], which also identified only two to date. Despite running and cycling both being aerobic cardiovascular exercises, they differ in glycogen depletion patterns and fat oxidation rates [143,145,171]. Whilst cycling depletion happens predominantly in the quadriceps and plantar flexors, due to the non-weight-bearing nature [171], running typically shows a more uniform glycogen depletion in several muscles, such as the gastrocnemius, quadriceps, plantar flexors, and gluteal muscles. These differences affect CHO-oxidation during exercise [145], and CHO-loading and glycogen replenishment strategies. On the other hand, fat oxidation is significantly higher in runners than in cyclists [143,145,171], further indicating the difference in fuel utilization between the sports. Evidence consistently shows that fat oxidation rates are higher in running compared to cycling, even when athletes are matched for training status [139,172]. As discussed in section 2.4, the difference likely reflects the greater active muscle mass and postural loading in running, which increase total oxidative demand. Running also elicits higher whole-body energy expenditure at a given relative intensity compared with cycling [73] which raises absolute fat oxidation rates. In addition, the distribution of workload across multiple muscle groups in running delays local glycogen depletion and allows sustained reliance on fat, whereas cycling tends to concentrate workload in fewer muscle groups, promoting higher carbohydrate dependence [73].

Despite clear differences, exercise science studies are predominantly conducted on cyclists instead of runners, potentially due to the ease of testing. Cycling offers many methodological advantages, such as convenient control of work rate and cadence, and the accessibility of cannula placement and blood draws whilst exercising. Due to the metabolic and physiological differences between the two sports, evidence found whilst cycling should not be hypothesized as being similar to running [171]. An example of this disparity is seen in the contrasting outcomes, with the reviewed studies on runners [106,129] showing no performance improvement from MCT supplementation, while some studies on cyclists [28,131] reported notable enhancements. Further

evidence of disparity is supported by the work of Pfeiffer, et al [145], who tested the differences in fat and CHO oxidation in cyclists compared to runners when ingesting a CHO or water drink. The authors noted differences in energy metabolism between the sports, with higher fat oxidation in the runners when ingesting the CHO drink compared to the cyclists, when exercising at 60% VO_2max [145]. This change in fat oxidation observed with CHO supplementation suggests a potentially greater glycogen-sparing effect in runners compared to cyclists. These findings highlight distinct metabolic responses between the two sports, emphasizing that nutrient strategies and their effects cannot be directly generalized across sports [145].

Another notable characteristic of the studies reviewed is the lack of gender diversity, as none included female endurance athletes. Notably, females experience higher fat oxidation compared to their male counterparts [140], which might enhance their metabolism of MCT. Other studies not included in this review include the work of Nosaka, et al [29,30], from 2009-2018 conducted on 7 women and one man [30], and 8 women [29] (These studies were not included in this review as the participants did not meet the inclusion criteria for endurance athletes.) Both studies incorporated similar experimental designs, including cross-over, and randomized trials, and examined the effects of MCT supplementation on cycling performance. The first study compared the effects of a pre-event meal comprising either MCT or LCT [30], as discussed in section 2.2.2.3, resulting in a longer cycle time until exhaustion and an increase in fat oxidation (> 0.4 $g.min^{-1}$) in the MCT group [30]. The second study compared MCT+CHO to CHO supplementation under similar conditions, where participants underwent a 40-minute cycle at 50% VO_2max, followed by a cycle to exhaustion at 70% VO_2max [29]. The MCT+CHO group cycled significantly longer than the CHO group, experiencing fat oxidation of 0.3 $g.min^{-1}$. Although both studies observed improved performance in the MCT groups, fat oxidation was similar to other studies involving MCT (0.3-0.5 $g.min^{-1}$). This indicates that gender may not affect MCT metabolism. However, many studies have observed increased rates of fat oxidation in women when compared to men, whilst running and cycling at varying intensities between 55-75% VO_2max [140,173,174]. Therefore, future research should include females to determine if the change in fat oxidation between genders results in differences in MCT usage.

Within this review, one cycling study observed the fastest TT times in the MCT+CHO groups when compared to MCT or CHO groups [28,131]. The study was conducted during a two-hour cycle followed by 40km TT [28]. Participants consumed a 400ml solution containing 4.3% MCT and 10% CHO (17 g MCT + 40 g CHO) before exercise, followed by 100ml doses at 10-minute

intervals equating to 68g over the two-hour cycle. The results showed an increase in BHB concentrations in the groups containing MCT, indicating an increase in FFA utilization. However, the slowest TT times were observed in the MCT group.

Blood analyses across the studies showed similar profiles in blood glucose, glycerol, FFA, BHB, and lactate concentrations. Consistently, plasma glucose concentrations were maintained in supplements containing CHO (4.5-5.5 mmol/L^{-1}) but declined gradually (< 4.0 mmol/L^{-1}) during exercise in the MCT only groups. The role of CHO in sustaining plasma glucose concentrations was discussed in section 2.2.1.3, highlighting its effectiveness in delaying fatigue by ensuring a continuous supply of glucose for muscle energy. This effect was evident in the improved performance of CHO containing supplement groups (including the MCT+CHO supplements), where euglycemic plasma concentrations were maintained, compared to the MCT only groups in a number of studies [15,28,52,126,131].

Angus, et al [52] suggested that their study's lower plasma glucose concentrations in MCT only groups reflected an increase in glycogen depletion. Opposing this, Van Zyl, et al [28] attributed the lower glucose concentrations in the MCT-only groups of their study to a reduced reliance on glucose, leading to decreased hepatic glucose release and lower blood glucose concentrations. This was further supported by the lower CHO oxidation rates observed in the MCT group compared to the CHO group in their study. Notably, adding MCT to CHO increased glucose availability, as observed in the MCT+CHO groups in the Horowitz, et al [126] study, where glucose concentrations were higher than in CHO only groups, thus indicating reduced CHO utilization in the combination group.

In four of the studies reviewed, glycerol concentrations increased over time during steady state exercise in all supplement groups, with no significant difference between groups [15,106,129,131]. During prolonged exercise, triglycerides undergo lipolysis, yielding free FFA and glycerol, thus increasing concentrations of both. The FFA are oxidized via beta-oxidation and enter the Krebs cycle for energy production, while glycerol can be utilized in gluconeogenesis. On the other hand, MCT are rapidly hydrolysed to medium-chain fatty acids (MCFA) and glycerol. MCFA are absorbed and transported directly to the liver, where they are quickly oxidized to provide energy, similar to glucose metabolism. This rapid oxidation of MCFA can elevate plasma total FFA and glycerol concentrations during exercise. Elevated glycerol levels are expected during unfed exercise due to increased lipolysis, providing a substrate for energy production. Ingested

MCT contribute to this process by increasing the availability of MCFAs and glycerol, which can be rapidly metabolized to meet energy demands during endurance activities [58].

To this end, this mechanism explains the observed increase in FFA concentrations when supplementing with MCT in five of the studies reviewed [15,28,52,131,169]. The rapid metabolism of MCT is attributed to findings from Beckers, et al [175] who demonstrated that co-ingestion of MCT and CHO accelerates gastric emptying. Their study tested four different drink solutions (CHO, or CHO+MCT, with the amount of MCT varying), showing that all drinks containing MCT increased the rate at which gut content left the gut. This faster gastric emptying likely further explains the rapid rise in circulating FFAs observed in MCT containing groups.

Furthermore, a similar pattern is seen in the increase of BHB in all MCT groups [15,28,52,131,169]. This may be due to the differences in metabolism and fuel utilization between MCT and CHO. MCT are rapidly absorbed and transported directly to the liver via the portal vein, after which they undergo beta-oxidation in the mitochondria, producing acetyl-CoA that can be used for ketogenesis. This results in the increased production of ketone bodies, including BHB, which are released into circulation. In contrast, CHO ingestion leads to glucose absorption and insulin release, which inhibits lipolysis and reduces the availability of free fatty acids for beta-oxidation [22,23,58]. Since glucose is the preferred energy source, ketogenesis is suppressed, resulting in minimal BHB production. Therefore, plasma BHB concentrations are significantly higher in MCT groups compared to CHO groups, as MCTs provide a direct precursor for ketone production even in non-ketogenic states, whereas CHO inhibits this process.

Although lactate did not significantly differ between groups in most of the studies, it was lower in the MCT groups than in the CHO groups in two studies [28,131]. As exercise intensity increases, so does the rate of glycolysis, leading to greater lactate production as a byproduct. While lactate itself is not a direct cause of fatigue, it serves as an indicator of glycolytic activity [176–178]. The lower lactate accumulation observed in MCT groups is likely due to a reduced ability to sustain the same intensity as CHO groups, as evidenced by the lower power output reported in the study by Jeukendrup, et al [131]. Participants of this study were unable to sustain the same power of the CHO and MCT+CHO groups, resulting in the slowest times to complete a 40km TT in the MCT group. This suggests that the reduced lactate levels are not a result of glycogen sparing but rather a reflection of a diminished capacity to perform at higher intensities.

GI discomfort is often experienced in endurance athletes [133], and was reported in seven of the nine studies within this review. The dosage of MCT remained under 35g in the majority of the

studies [28,52,126,129,168,169], whilst Misell, et al [132] and Jeukendrup, et al [179] used higher doses of 60 and 85g, respectively, both resulting in severe GI discomfort. However, despite the initial discomfort observed by Misell, et al [132] the authors noted symptoms diminished over the two weeks, suggesting gut-training of MCT is possible. Athletes often use gut training during training runs to reduce GI sensitivity to foods and supplements [133,136] as discussed in Chapter 2, section 2.3. Therefore, incorporating MCT supplementation during training runs is a practical recommendation to enhance tolerance and optimize performance. Additionally, pairing MCT with CHO may further reduce discomfort in runners accustomed to CHO ingestion.

None of the cycling studies in this review administered MCT on the days leading up to exercise. Instead, MCT was ingested within the hour before and during exercise, impacting the metabolism, absorption, and utilization when exercising. If ingested during rest, when energy requirements are low, MCT is metabolized and stored as FFA in the liver or in adipose tissue for later use [1,39]. During exercise, as energy requirements increase, FFA are then released into the bloodstream, entering the muscle cell via the carnitine shuttle [1,39]. This process of mobilizing stored FFA for use during exercise is substantially slower than the use of available MCT. Therefore, ingesting MCT directly before or during exercise will enable rapid use [163].

Macronutrient timing has been thoroughly researched, and recommendations are given for the days and hours before, during, and after exercise. Indeed, ingesting CHO days, hours, or immediately before exercise each has significant effects on exercise performance [73] as discussed in sections 2.2.1.1-2.2.1.3. Perhaps the same gravity should be given to MCT ingestion. As the most successful timing of MCT ingestion in cyclists is directly before and during exercise [28–30] future research in runners should consider the same to better align with metabolic requirements.

Whilst none of the cycling studies in this review accounted for the habitual diets of the participants, the running studies required participants to follow a low-fat diet in the weeks before exercise testing [129,132]. The reason for doing so is not discussed in either paper, but the hypothesized effect is reduced efficiency in MCT utilization. Previous evidence by Burke, et al [115], who tested the metabolic effects of following either an HC or HF diet for 5 days, found the HF group's fat oxidation was double that of the CHO group ($0.4 g.min^{-1}$ and $0.8 g.min^{-1}$, respectively) during two hours of steady-state cycling at 70% VO_2max. To this end, following

a HF diet before exercise testing would have further increased participants' ability to oxidize MCT, potentially resulting in exercise enhancement.

During long-duration exercise, athletes are prone to experiencing hypoglycaemia without the use of CHO ingestion, as discussed in section 2.2.2. This is seen in the MCT only groups within many studies of this review, which resulted in the slowest TT times [28,52,131,168] when compared to the CHO or MCT+CHO groups. Particularly, euglycemia was observed in all groups containing CHO, but concentrations decreased below 3.3 mmol/L^{-1} in MCT only groups during two hours of cycling [131]. Based on the results from this review and others [130,170] MCT, when used alone, is not beneficial for exercise and requires the addition of CHO to facilitate improved performance through the maintenance of blood glucose.

3.5 Conclusions

This review aimed to assess the effects of MCT supplementation on endurance performance. The lack of literature on running is noteworthy, indicating a clear gap in current knowledge. In the studies reviewed, improved performance was only observed in two studies, which combined MCT with CHO, and were ingested within one hour and during exercise. Conditions, including CHO, maintained stable plasma glucose concentrations, while MCT-containing supplements increased fat metabolism and ketone production. Lower lactate concentrations observed during TT scenarios in the MCT groups likely reflect reduced exercise capacity, as evidenced by slower TT times, rather than improved metabolic efficiency. Many inconsistencies were found in the timing and dosage of MCT ingestion, and future research should focus on improving these factors as well as incorporating gut training and the combination of CHO and MCT in hopes of improving performance.

3.6 Limitations

This scoping review had limitations, including the variations of MCT ingestion between studies, such as the timing and dosage, which provided challenges when comparing results. Additionally, the habitual diet of the participants was only controlled for in two of the eight studies reviewed, further complicating results. The exercise protocols differed between studies, with the majority of them including steady-state exercise followed by maximal all-out running or cycling, whilst two of the studies did not include any steady-state exercise.

A notable gap identified in this review is the lack of recent literature on MCT supplementation and endurance performance, with most studies conducted before 2005. The reliance on older

studies raises concerns about the relevance of findings to current athletes, whose training and dietary habits may have evolved. This gap highlights the need for renewed research to ensure findings remain applicable to current endurance sports practices. The same can be said regarding the small number of studies to review on runners and females, highlighting a significant gap in the literature on the effects of MCT and endurance performance. Alternatively, this could be viewed as a strength of this scoping review, as it highlights a clear rationale for future investigations.

Chapter Four: An Investigation of the Effects of Medium-Chain Triglycerides and Carbohydrates on Running Performance in a Randomized Cross-over Trial.

Chapter Introduction

In Chapter 3, a scoping review examined the effects of MCT on endurance performance, highlighting a significant research gap in running, as most studies focused on cycling and none included female endurance athletes. While the combination of MCT and CHO showed potential performance benefits, findings were highly variable, often limited by GI discomfort. Moreover, inconsistencies in study methodologies further complicate the interpretation of results. Building on these findings, this chapter outlines a detailed methodological framework designed to address the research gaps identified in Chapter 3. Using a randomized crossover design, this study investigates the effects of MCT, CHO, and MCT+CHO supplementation on endurance running performance. By applying a structured and controlled approach, this study aimed to provide clearer insights into the role of MCT in running, overcoming the limitations and inconsistencies observed in previous research.

Abstract

Objective: This crossover experimental trial investigated the effects of supplementing with medium-chain triglycerides (MCT) and carbohydrates (CHO) on exercise performance in endurance runners. **Methods:** The protocol used a randomized, single-blind, cross-over study design. Following an overnight fast, participants ingested a CHO meal (consisting of ± 60g CHO) of their choice three to four hours before arriving at the lab for testing. Participants completed three testing sessions, each consisting of a 90-minute run at 75% VO_2max followed by a 5 km time trial. During each session, they randomly received one of three supplements: MCT (4.3%), CHO (10%), or MCT+CHO (4.3% + 10%), which were ingested in 15-minute intervals during the 90-minute run. Measured outcomes included substrate utilization, VO_2, RER, CHO, and fat oxidation, blood analyses (plasma glucose, serum lactate, FFA, BHB, and glycerol), HR, RPE, and TT time. **Results**: The experimental trial revealed reduced running economy in the MCT+CHO (44.9 $ml.kg^{-1}.min^{-1}$) compared to the CHO (42.2 $ml.kg^{-1}.min^{-1}$) and MCT (43.6 $ml.kg^{-1}.min^{-1}$) groups, and an increase in fat oxidation in the MCT group (0.5 ± 0.3 $g.min^{-1}$) compared to the CHO and MCT groups (0.3 ± 0.2 $g.min^{-1}$ for both groups) ($p < 0.001$) during the 90-minute submaximal run. The combination of MCT+CHO resulted in reduced HR and RPE compared to the MCT condition ($p = 0,0003$), and the use of CHO reduced GI discomfort compared to the MCT group (0.4 ± 0.9 and 1.6 ± 1.9, respectively) (p

= 0.0001). **Conclusion:** Although the combination of MCT and CHO may reduce running economy during steady-state exercise, it may hold the potential to reduce gut discomfort.

4.1 Introduction

Comparing the efficacy of HC and HF diets on endurance performance has been researched for many decades [44,115,180]. The evidence available on the use of HF to enhance exercise performance is discussed in section 2.2.2.1. This section highlighted that, despite changes in substrate utilization, most studies to date have reported no clear improvement in exercise performance [126], with two studies noting reduced exercise capacity and slower TT times [6,110]. Indeed, despite multiple research attempts to utilize the benefit of increased fat oxidation to improve performance, there is only a limited amount of evidence showing improved exercise performance at moderate intensities [27,181]. Investigations effective in improving exercise performance used a combination approach of habitual HF diets with CHO-loading. Such research has proven that CHO-loading does not affect the body's ability to maximize fat oxidation during exercise, once fat-adapted [27].

In addition to diet, Chapter 3 showed multiple research efforts that examined the impact of MCT supplements on endurance sports. These studies include well-trained cyclists [28,37,167–169,179,182], university students [29,30], and endurance runners [129,132]. Although none of the reviewed studies resulted in improved performance in the MCT groups, the combination of MCT+CHO improved TT performance in two of the cycling studies [28,30].

Two recent systematic reviews [130,170] identified only two experimental trials that investigated the effects of MCT in runners [129,132]. Furthermore, Chapter 3 of this thesis highlighted that no literature was evident on female endurance runners, or since 2005. Lastly, the literature review in Chapter 2, highlights that although HF and HC diets have been compared individually and in combination, as have HC supplements, the combined use of these diets and supplements has not been investigated.

This experimental study aimed to address these gaps by utilizing a randomized, crossover design to compare the effects of supplementing with either CHO, MCT, or MCT+CHO during running performance.

4.2 Methods

4.2.1 Aim and Hypothesis

This randomized, crossover, single-blinded study aimed to investigate the effects of a HF combined with CHO-loading and subsequent supplementation with MCT, CHO, or MCT+CHO on running performance in endurance runners. We hypothesized that the combination of a habitual HF diet, paired with two days of CHO-loading, followed by MCT+CHO supplementation, would result in improved performance and faster TT times.

4.2.2 Population and Sample Selection

Male and female endurance runners capable of completing a half-marathon (21km) under one hour 40 minutes (males) or two hours (females) within the last year, who were over 18 years old, were recruited. Participants were injury-free with no chronic/ lifestyle diseases and were following their habitual diet for at least four weeks [183]. Runners whose training had been inconsistent in the past six months were excluded.

4.2.3 Participant Recruitment

Twenty endurance runners were recruited for the study by contacting local running clubs and posting adverts on social media (Appendix A). Participants interested in taking part in the study were given a Participant Information Sheet (Appendix B) to read, and a consent form to complete (Appendix C). To ensure the participants met the inclusion criteria, they were given a Participant Questionnaire to complete (Appendix D).

When commencing recruitment, the study aimed to recruit runners following either a HC diet (daily consumption of CHO > 60% total intake [184,185]) or HF diet (daily consumption of fat = 60-75% total intake [2,41,42,109]). However, of the 20 participants recruited, all reported following a habitual diet moderate-high in CHO, and none were willing to consider following a HF diet. When trying to recruit additional participants following a HF diet, no participants made themselves available or showed interest in the study. Due to this, the element of comparing dietary interventions was removed from the original study design, and only the three supplement conditions were compared.

4.2.4 Baseline measurements

Participants were asked to refrain from any unaccustomed exercise on the day before testing. A 3-day dietary and training record was completed (two weekdays and one weekend day) to

determine the energy and macronutrient intake of the participants (Appendix E and F). Individuals were instructed regarding serving sizes, supplements, beverages, food preparation, and other variables that could influence the estimation of diet composition. Although there are more accurate and thorough measurements of daily intake, the 3-day food log has been successfully used in similar exercise trials to monitor intake and ensure consistent eating habits throughout testing [27,98,106,129,158]. Diet was analysed using the Calorie Counter by Cronometer (Cronometer Software Inc, 2011) to determine daily energy and macronutrient intake. Participants were asked to repeat their normal weekly training before subsequent testing. Anthropometric testing [height, weight, Body Mass Index (BMI), and the sum of 4 skinfolds (bicep, triceps, subscapular, and suprailiac)] was reported [186]. This was followed by a Peak Treadmill Running Speed Test (PTRS) to determine the speed for a subsequent 90-minute steady-state running trial. The peak treadmill speed test began with each runner being allowed to follow a warmup of their choice, as they would normally do before a race, TT, or track workout. Following this, the participant started running at a speed one $km.hr^{-1}$ slower than their normal training speed, with the velocity being increased by 0.5 $km.hr^{-1}$ every half minute until voluntary exhaustion. Peak treadmill running speed was defined as the maximum mean treadmill speed sustained for any consecutive 30-second period during the PTRS test. Any subsequent speed achieved for less than 30 seconds was not considered. Immediately after, a 5km TT familiarisation run was used to minimize any learning effect in the subsequent trials.

4.2.5 Experimental Tests

Each participant attended three testing days, one for each of the three supplements - either the CHO, MCT, or MCT+CHO supplement, the order of which was randomly assigned. The participants were blind to which supplement they were given. There was a 14-day washout period between testing days. Participants continued tracking their macronutrient intake throughout testing and during each washout period by completing a 3-day dietary record each week. This ensured participants continued following their habitual diets throughout testing (throughout testing refers to the time that the participants started their baseline measurements, up until their final running trial. Typically, covering a duration of 8 - 10 weeks). Each participant was tested at similar times for each visit, preferably in the morning. Female participants were tested at four-week intervals so that visits occurred at consistent points in their self-reported cycle. The specific menstrual cycle phase at the time of testing was not recorded; however, all women reported regular, approximately 28-day cycles. This scheduling approach was used to reduce between-trial variability associated with cycle timing.

A CHO breakfast containing 60-65g CHO was consumed three to four hours before scheduled testing to enable optimal digestion and absorption and avoid reactive hypoglycaemia [3]. The food type was determined by the preference of the runner to avoid any undesirable GI tract discomfort.

The experimental trials comprised a 90-minute steady-state treadmill running protocol at 75% of peak treadmill speed, followed by a 5km TT on a laboratory treadmill. While laboratory studies cannot perfectly replicate outdoor running conditions, they are often the most practical method for testing exercise performance due to the greater accuracy and reliability of measurements. In this context, Jones, et al [187] demonstrated no meaningful difference between treadmill and track running performance when the treadmill is set at a 1% gradient. This small incline accounts for the reduced air resistance indoors and better reflects the energetic cost of overground running. Furthermore, similar protocols, including steady-state exercise followed by TT, have been frequently used in studies investigating the efficacy of MCT supplementation in cycling studies [28,132,168].

HR was measured along with the rating of perceived exertion (RPE) in 15-minute intervals throughout the 90-minute run. HR was measured using a Garmin HRM-Dual Heart Rate Sensor (Olathe, Kansas, United States), and RPE was measured using the Borg scale [188] by asking each participant to rate their perceived exertion on a scale of 1-10. Blood was taken via venous blood draws at the same intervals to determine plasma glucose, glycerol, lactate, FFA, and beta-hydroxybutyrate (BHB) concentration. In addition, at the time of the 15-minute test intervals, respiratory exchange ratio (RER) and oxygen consumption (VO_2) were measured by a breath-by-breath pulmonary gas exchange measuring system (Cosmed, Omnia Health, Chicago, Illinois, USA).

After the final measurements were taken at the end of the 90-minute steady-state run, participants were allowed to void their bladder before commencing the 5 km TT. The duration of this break was not standardised, as it varied slightly depending on individual needs. However, participants proceeded directly to the TT without unnecessary delay, and the short variation in time was not considered sufficient to influence outcomes.

During the 5km TT, only HR, RPE, and time-trial performance times were measured.

4.2.6 Diet and Supplementation Protocol

Participants continued to follow their habitual diets throughout the study. In addition, prior to each experimental trial, they completed two days of carbohydrate loading (10 $g \cdot kg^{-1} \cdot d^{-1}$) in line with current best practice to ensure adequate glycogen stores [53,189]. Dietary guidelines and instructions were provided by a registered dietician, detailing the diet to follow during the CHO-loading phase.

4.2.7 Supplements

The supplements consisted of 10% CHO, 4,3% MCT, or CHO (10%) + MCT (4,3%). The CHO supplement was a glucose polymer, and the MCT supplement comprised 60% caprylic and 40% capric fatty acids. The supplements were ingested in 15-minute intervals during the 90-minute steady-state run. Total CHO intake was 60 $g.hr^{-1}$ [189], and MCT of < 30$g.hr^{-1}$ (4.3% x 150ml = 25.8 $g.hr^{-1}$) [129].

4.2.8 Gaseous Exchange

During the constant load 90-minute sub-maximal run, RER and VO_2 were measured by a breath-by-breath pulmonary gas exchange measuring system (Cosmed, Omnia Health, Chicago, Illinois, USA). The gas exchange measurement system was calibrated before testing according to the manufacturer's instructions, with the O_2 and CO_2 analyzers using gases of known concentration (O_2 = 16%, CO_2 = 5%) and the turbine flow meter with a calibrated 3L syringe. VO_2 and VCO_2 were measured at 15-minute intervals via a mouthpiece connected to the transducer of the VO_2 measuring apparatus. During each interval, expired air was sampled for 2-3 minutes, and VO_2, CO_2 production, and RER were determined by averaging consecutive 10-second periods. The VO_2 data, expressed in units of $ml.kg^{-1}.min^{-1}$, were screened to eliminate outlier breaths exceeding 4 standard deviations, with corresponding CO_2 and O_2 volume values removed accordingly. The corrected data was averaged into 10-second intervals. RER was calculated as VCO_2/VO_2, and overall rates of CHO and fat oxidation in $g.min^{-1}$ were calculated using the Frayn equation, assuming a non-protein RER: Fat oxidation rate ($g.min^{-1}$) = 1.695 VO_2 – 1.701 VCO_2. CHO oxidation rate ($g.min^{-1}$) = 4.585 VCO_2 – 3.226 VO_2. VCO_2 is the volume of carbon dioxide in expired air in $L.min^{-1}$, and VO_2 is the corresponding oxygen uptake in $L.min^{-1}$.

4.2.9 Blood Analyses

Blood was taken via venous blood draws at baseline and 15-minute intervals during the 90-minute sub-maximal running protocol. For each draw, 10 mL blood samples were taken using a 21-gauge cannula attached to a three-way stopcock and positioned in a forearm antecubital vein. One aliquot (3 ml) was placed into a tube containing potassium oxalate and sodium fluoride (FI/Ox) for subsequent analysis of plasma glucose. Another aliquot (5 ml) was placed into a tube with a gel and clot activator (SST) for analysis of serum glycerol and BHB concentrations. All samples were placed on ice until centrifuged at 3000 rpm at 4°C for 10 minutes upon completion of the trial. The resulting supernatants were stored at -20°C for later analysis. Plasma glucose samples were analysed by a commercial laboratory (Lancet Laboratories). Serum samples were analysed using various Elabscience (Houston, United States) Metabolism Assay Kits. These included the following kits: E-BC-K340-M for glycerol, E-BC-K785-M for BHB, E-BC-K792-M for free-fatty acids, and E-BC-K044-M for lactate.

4.2.10 Gastrointestinal Tract Discomfort

GI symptoms of participants were recorded at 15-minute intervals throughout the experimental trial. GI symptoms were classified as "upper" and "lower." "Upper" included excessive belching, a feeling of being bloated, stomach cramps, nausea, or vomiting. "Lower" referred to excessive flatulence, an abnormal urge to defecate, or diarrhoea. The severity of symptoms was rated from 0-5, with 0 = no symptoms and 5 = severe enough symptoms to interfere with exercise performance. A score of < 3 was considered mild and > 3 was severe [190].

4.2.11 Calculating Resting Metabolic Rate

To calculate the estimated resting metabolic rate (RMR) the following calculations were used based on the Harris–Benedict Equation [191]

Men = 88.362 + (13.397 x weight [kg]) + (4.799 x height [cm) − (5.677×age [y])

Women = 447.593+(9.247×weight [kg])+(3.098×height [cm])−(4.330×age [y])

4.2.12 Data and Statistical Analysis

To calculate an appropriate sample size for the proposed study, G*Power 3.1 software was used using the default settings with parameters set as follows: statistical test = ANOVA: Repeated measures, within factor, effect size = .30, α = .05, statistical power (1 - β) = .8, number of

conditions = 1, and number of measures = 3. The analysis suggested that N = 10 would be sufficient to detect a medium-sized effect between the three supplement conditions.

Data were analysed using a repeated measures ANOVA using *lme4* package [178], with supplement type and time as fixed effects, and participants included as a random effect to account for within-subject variability. Results were interpreted as statistically significant if *p-values* were less than 0.05. Where significant effects were found, pairwise comparisons with Tukey HSD methods were used to compare estimated marginal mean differences in the outcome variables using the *emmeans* package. The normality of the data was assessed using the Shapiro-Wilk test and Q-Q plots. All non-normal data were log-transformed prior to analysis; thereafter, results were exponentiated for easier interpretation.

4.3 Protocol Rationale

Endurance running performance relies heavily on sufficient fuel availability. The current recommendations for the days before an event are covered in section 2.2.1.1, as are the recommendations for the pre-test meal in section 2.2.1.2. Additionally, recommendations for supplementing with CHO during exercise to maintain blood glucose concentrations [180] were presented in section 2.2.1.3. To this end, all participants, irrespective of habitual diet CHO-loaded two days before testing (8-12 $g.kg^{-1}.day^{-1}$ CHO). On the morning of testing, following an overnight fast, participants then ingested a HC meal three hours before exercise testing. This time frame was chosen to allow for complete metabolization and absorption, ensuring baseline concentrations (glucose and insulin) were back to normal before testing. During the trial, participants in the CHO condition ingested 15g CHO every 15 minutes, or 60 $g.hr^{-1}$, following current optimal practice.

In designing the CHO ingestion amount, 60 $g.hr^{-1}$ was selected as a conservative yet physiologically relevant intake for trained endurance runners. This level is well-supported in the sports nutrition literature and is frequently tolerated without severe GI distress in running protocols. For instance, Moodley, et al [192], observed effective exogenous CHO oxidation using glucose polymers at moderate concentrations in cycling, as did Raunch, et al[193] during ultra-endurance exercise. Although the addition of sodium alginate and pectin hydrogels to CHO solutions can enhance early gastric emptying and potentially reduce GI discomfort [194], this was not used in the CHO containing conditions, as evidence does not reliably show performance enhancement above conventional CHO solutions [195].

Moreover, the amount of 60g was chosen as tracer studies and meta-analyses suggest that exogenous CHO oxidation rates plateau near ~1.0 g·min⁻¹ (≈ 60 g·h⁻¹) when ingesting glucose alone [81], and that higher oxidation rates (~1.3–1.75 g·min⁻¹) depend on using combined glucose + fructose formulas [196]. In running, the mechanical impact, vertical motion, and greater GI stress compared to cycling impose additional constraints on high CHO tolerance. For ultra-endurance contexts, while total CHO demands increase, the lower per-minute power output reduces metabolic pressure, making excessive ingestion beyond oxidation capacity unnecessary and potentially counterproductive. Thus, 60 g·h⁻¹ offers a balanced compromise between maximizing substrate availability and minimizing GI risk.

The carbohydrate solution used in the present study was provided at ~10% concentration, and was selected because glucose polymers at ~10% maintain relatively low osmolality, thereby promoting effective gastric emptying and intestinal absorption compared with equivalent glucose solutions [197]. While commercially available sports drinks often range between 6–8% CHO, higher concentrations have frequently been employed in controlled studies to maximize substrate delivery during endurance protocols [192]. The risk of gastrointestinal distress at higher CHO concentrations is recognized, particularly in running due to the mechanical stress of foot strike and vertical oscillation [135]. However, given that all participants in this study reported regular use of sports drinks and gels in training, it was anticipated that tolerance would be sufficient. Accordingly, the chosen concentration represents a balance between maximizing exogenous carbohydrate availability and maintaining practical tolerability in trained distance runners.

The dosage and timing of MCT supplementation are less understood, and the optimal protocol remains unknown. Evidence from Chapter 3 proves MCT is most effective when administered during exercise in 15-minute intervals [28–30], and not on the days leading up to exercise [129,132]. In line with successful studies, MCT was administered in 15-minute intervals during exercise to facilitate metabolism [20,28]. To mitigate potential gut discomfort associated with MCT supplementation, the study adhered to a dosage not exceeding (4,3%) 30g per hour, based on previous findings [20,29,30,132,198].

It is common for endurance runners to run long distances, such as a marathon, at a high intensity (> 85% VO_2max) during race scenarios [199]. Therefore, the protocol involved a 90-minute run at 75% of VO_2max, followed by a maximal effort 5km time-trial, to best assess real-world performance as noted in section 2.4. Additionally, these intensities were chosen to investigate

if MCT can be oxidized at such high intensities. Previous studies have observed increased fat oxidation above 0.5 g.min^{-1} when supplementing with MCT at 60-80% VO_2max in cyclists [28–30,37,44], without HF dietary intervention.

The scarcity of evidence on MCT and runners was expressed in Chapter 3. Thus, this study chose to conduct the experimental trial on runners to lessen the gap in understanding the effects of MCT during different exercise types. Additionally, this study used both male and female runners to collect evidence across genders, which has not yet been conducted in other research.

4.4 Results

The participant characteristics are presented separately for males and females, as well as the energy intake and expenditure estimations. However, all other results are presented as one sample, regardless of gender, due to sample size. While gender-specific differences in oxygen consumption and substrate utilization are acknowledged, they are considered marginal [200,201]. The differences observed in supplement intake are more substantial than gender-related variations, justifying the presentation of results as a single sample. Additionally, menstrual cycle effects were controlled by ensuring that female participants were tested at the same phase of their cycle during each session

4.4.1 Participant Characteristics

The participant's characteristics are summarised in Table 5.

Table 5. Characteristics of participants by gender.

Participants (n = 10)	**Males (n = 6)**	**Females (n = 4)**
Age (years)	35 ± 10	29 ± 3
Height (cm)	180 ± 4,5	166 ± 5
Weight (kg)	66 ± 8	645 ± 10
BMI (kg/m^2)	21 ± 2	24 ± 2
The sum of skinfolds (mm)	35 ± 10	42 ± 3
Mean best 21km (hr: min: sec)	01:26:10 ± 00:07:41	01:46:45 ± 00:13:04
Mean race pace per km (min: sec)	04:33 ± 00:16	05:08 ± 00:36
Peak Treadmill Speed (km.hr^{-1})	21,6 ± 4,2	17 ± 2,6
Baseline VO_2max (ml.kg^{-1}.min^{-1})	64,7 ± 2,2	61,3 ± 5,6
Running distance per week (km)	60 ± 20	43 ± 13

VO_2max = maximal oxygen consumption, BMI = body mass index. Values are means ± SD.

4.4.2 Habitual Diet

The mean estimated energy intake and expenditure for the male and female participants per day is presented in Table 6. Of the participants, 30% did not meet their daily calorie requirements. The habitual intake of the participants was 46% CHO, 19% protein, and 33% fats. None of the participants consumed a diet consisting of more than 56% CHO (Table 7).

Table 6. Estimated daily energy intake and expenditure by gender.

	Males (n = 6)	**Females (n = 4)**
Total Consumption (kcal)	2586 ± 411	2348 ± 1159
Total Expenditure (kcal)	2518 ± 319	2378 ± 214
Daily RMR (kcal)	1610 ± 168	1614 ± 142
Daily Running Energy Expenditure (kcal)	556 ± 155	376 ± 93
Exercise Energy Expenditure (non-running) (kcal)	199 ± 110	227 ± 110

RMR = resting metabolic rate, kcal = kilocalories. Values are Mean ± SD.

Table 7. Estimated daily macronutrient intake.

Macronutrients	**Total amount (g)***	**Calories (KCal.day^{-1})***	**% of total intake***
Carbohydrates	292 ± 107	1166 ± 430	46 ± 8
Protein	120 ± 34	479 ± 135	19 ± 6
Fats	91 ± 35	820 ± 317	33 ± 8

*Values do not include “other” energy intake, such as from alcohol, and do not equate to 100% of energy intake.

4.4.3 Experimental Running Trials: 90-Minute Submaximal Run

4.4.4 Oxygen consumption

The VO_2 values are depicted in Figure 2. Post hoc analyses revealed significant differences between all three supplement conditions, but not over time. The highest VO_2 was associated with the MCT+CHO condition (44.9 ± 4.4 ml.kg^{-1}.min^{-1}) when compared to the MCT (43.6 ± 3.3 ml.kg^{-1} .min^{-1}) ($p = 0.0004$) and CHO conditions (42.2 ± 4.3 ml.kg^{-1}.min^{-1}) ($p < 0.001$).

4.4.5 Respiratory Exchange Ratio

The RER varied across all three supplement conditions but showed no interaction with time. Post-hoc analysis showed the CHO condition had the highest mean RER (0.95 ± 0.06) when compared to the MCT+CHO (0.93 ± 0.05) ($p = 0.024$) and MCT conditions (0.90 ± 0.06) ($p < 0.001$), as depicted in Figure 3.

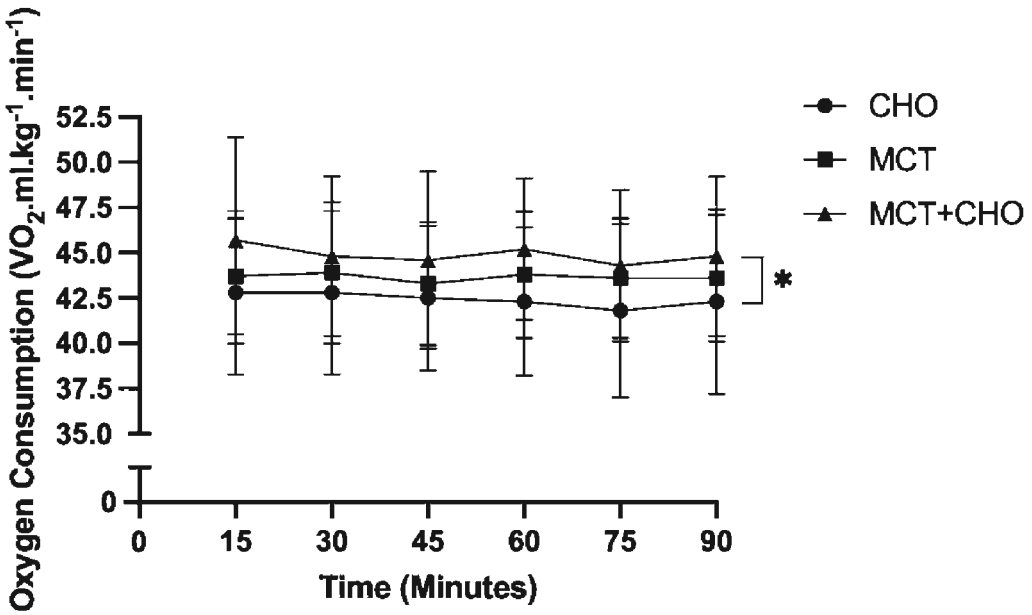


Figure 2. Mean oxygen consumption (VO_2) for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between all three supplement conditions ($p < 0.05$).

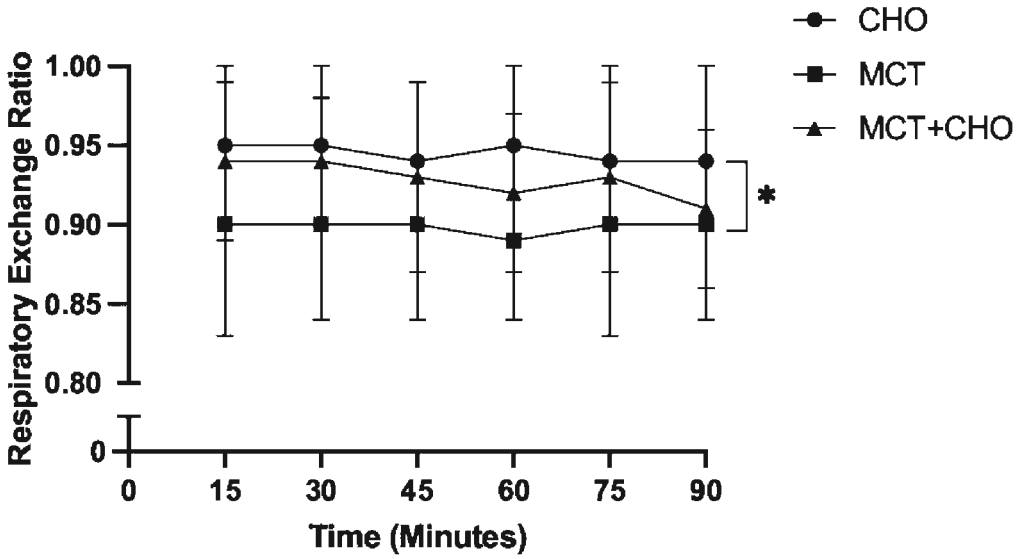


Figure 3. Mean respiratory exchange ratio (RER) for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between all three supplement conditions ($p < 0.05$).

4.4.6 Carbohydrate and fat oxidation

The CHO and fat oxidation are presented in Figures 4 and 5. The MCT condition (2.32 ± 0.76 $g.min^{-1}$) had significantly lower CHO oxidation compared to the CHO (2.78 ± 0.58 $g.min^{-1}$) ($p < 0.001$) and MCT+CHO (2.77 ± 0.79 $g.min^{-1}$) ($p < 0.001$) conditions when averaged over time. However, there was no significant difference between the CHO and MCT+CHO conditions ($p = 0.989$), indicating that the observed values were almost identical. Similarly, there was no significant difference between the fat oxidation of the CHO condition (0.33 ± 0.21 $g.min^{-1}$) compared to the MCT+CHO condition (0.34 ± 0.22 $g.min^{-1}$) ($p = 0.989$), which were almost identical, once again. However, the MCT condition (0.05 ± 0.29 $g.min^{-1}$) had significantly higher fat oxidation compared to the CHO ($p < 0.001$) and MCT+CHO ($p < 0.001$) conditions when averaged over time.

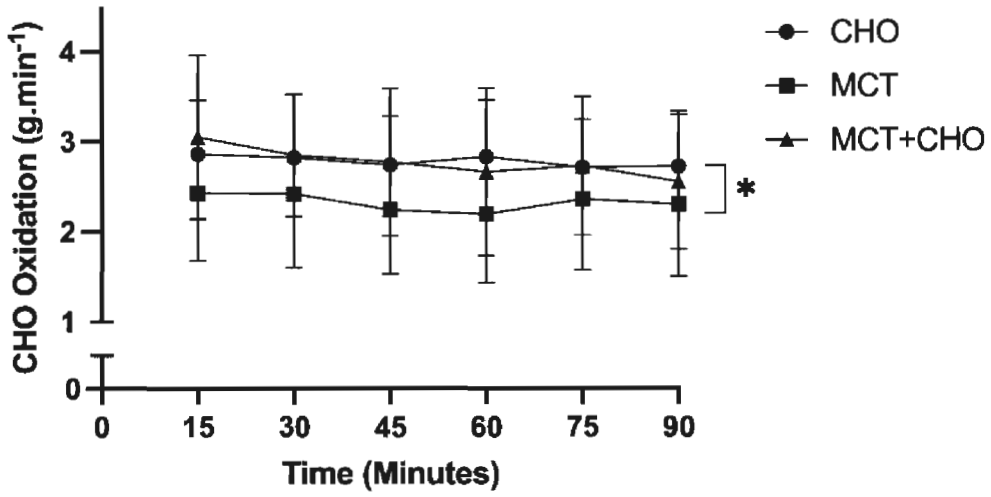


Figure 4. Mean CHO oxidation for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between the MCT condition and the CHO and MCT+CHO conditions ($p < 0.001$).

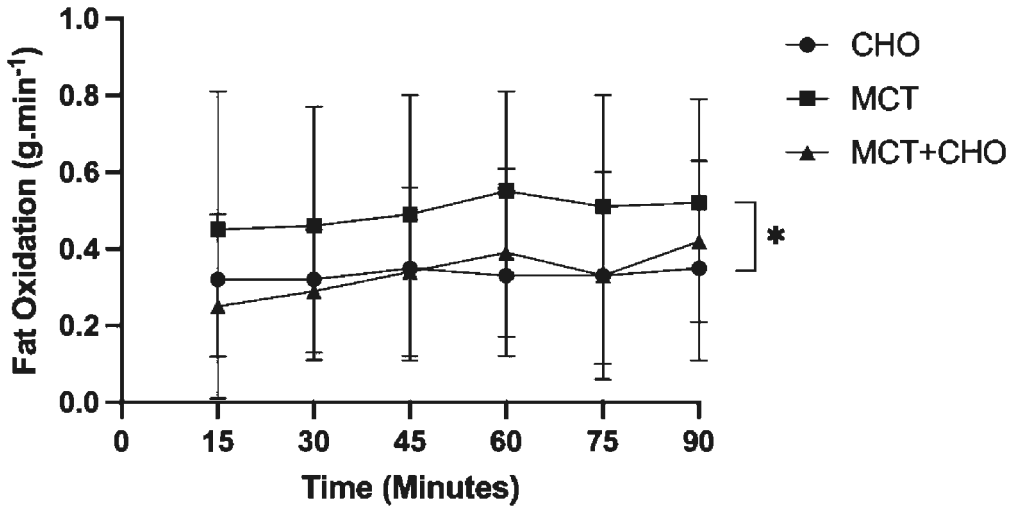
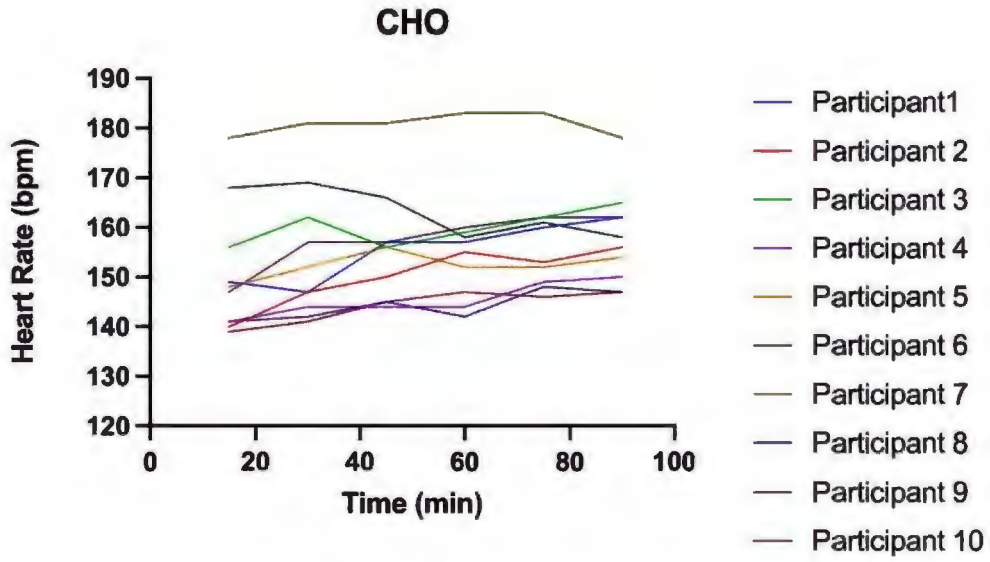
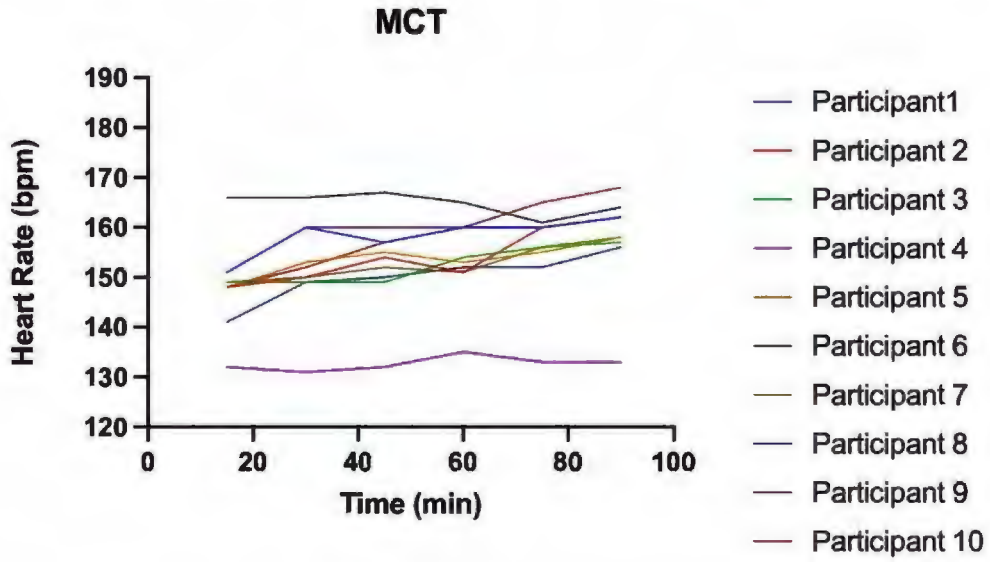


Figure 5. Mean fat oxidation for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between the MCT condition and the CHO and MCT+CHO conditions ($p < 0.001$).

4.4.7 Heart Rate and Rating of Perceived Exertion

The CHO condition had a significantly higher HR compared to the MCT+CHO condition ($p < 0.0147$) when averaged over time (Table 8). Post-hoc analyses of the RPE values revealed a significant difference between MCT and CHO ($p = 0.0064$) and between MCT and MCT+CHO ($p < 0.0001$) (Table 8). However, no significant differences were identified between the CHO and MCT+CHO supplement conditions ($p = 0.5104$). RPE was the highest in the MCT condition (6.5 ± 1.1) and lowest in the MCT+CHO condition (5.9 ± 1.3) ($p = 0.0001$). These results were averaged over time through the 90-minute run. Upon visual inspection of individual responses, natural inter-individual variability in HR was observed across supplement conditions, as seen in Figure 6.


CHO
Heart Rate (bpm)
190
180
170
160
150
140
130
120
0
20
40
60
80
100
Time (min)
Participant1
Participant 2
Participant 3
Participant 4
Participant 5
Participant 6
Participant 7
Participant 8
Participant 9
Participant 10


MCT
Heart Rate (bpm)
190
180
170
160
150
140
130
120
0
20
40
60
80
100
Time (min)
Participant1
Participant 2
Participant 3
Participant 4
Participant 5
Participant 6
Participant 7
Participant 8
Participant 9
Participant 10

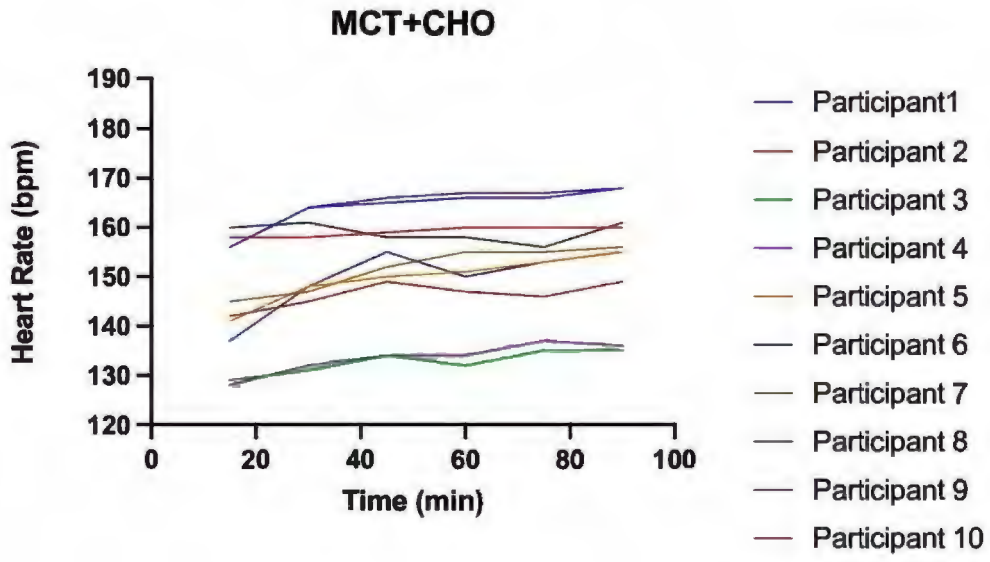

MCT+CHO
Heart Rate (bpm)
190
180
170
160
150
140
130
120
0
20
40
60
80
100
Time (min)
Participant1
Participant 2
Participant 3
Participant 4
Participant 5
Participant 6
Participant 7
Participant 8
Participant 9
Participant 10

Figure 6. Individual responses across all three supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean with no SD.

4.4.8 GI Tract

The repeated measures ANOVA showed significant differences between the supplement conditions and time ($p < 0.001$) on GI tract symptoms (Figure 7), but no difference between supplement conditions and time interaction ($p = 0.21$). Post-hoc analyses indicated significantly higher GI tract symptoms in MCT compared with CHO ($p < 0.0001$) and in MCT+CHO compared with CHO ($p = 0.0003$). Estimated marginal means showed that the MCT condition was associated with the highest GI tract symptoms, followed by MCT+CHO and CHO, respectively.

Table 8. Heart rate, Rating of Perceived Exertion, and GI Discomfort during the 90-minute run.

Condition	HR (bpm)	RPE	GI Tract
CHO	155 ± 11^{a}	6.1 ± 1.1^{a}	0.4 ± 0.9^{b}
MCT+CHO	151 ± 11^{b}	5.9 ± 1.3^{a}	1.2 ± 1.5^{ab}
MCT	154 ± 9^{ab}	6.5 ± 1.1^{b}	1.6 ± 1.9^{a}

Values are presented as mean ± SD for heart rate (HR), rating of perceived exertion (RPE), and gastrointestinal (GI) tract symptoms and are averaged over time across the steady-state run for each supplement condition. Superscript letters denote pairwise differences between conditions ($p < 0.05$). Conditions sharing a common superscript letter are not significantly different. Values were average over time.

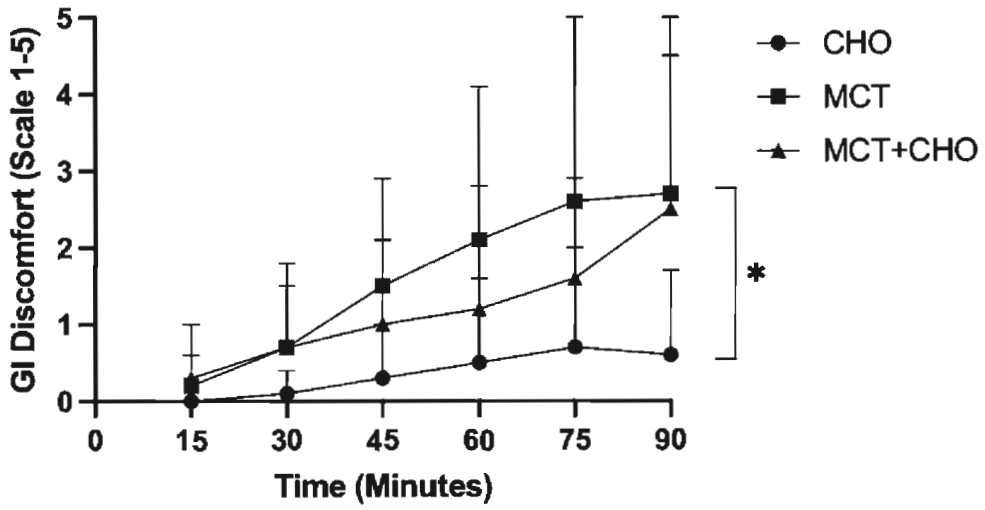


Figure 7. Mean gastrointestinal tract discomfort (GI tract) for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between CHO and MCT ($p < 0.0001$) and between CHO and MCT+CHO ($p = 0.0003$).

4.4.9 Blood Analyses

4.4.9.1 Serum Glycerol, Free-Fatty Acids, and Beta-Hydroxybutyrate

Glycerol concentrations are shown in Figure 8. Post-hoc analyses revealed that glycerol increased significantly from baseline to 30, 60, and 90 minutes ($p < 0.001$). However, concentrations did not differ significantly between consecutive intervals (30–60 and 60–90 minutes), indicating that the most notable increase occurred in the first 30 minutes, after which levels stabilised across all supplement conditions. No differences were seen between conditions ($p = 0.403$).

No significant changes were seen in the FFA concentrations between conditions ($p = 0.349$), as seen in Figure 9. Serum concentrations increased over time, with the most significant increases occurring between baseline and 60 minutes of exercise in all three supplement conditions ($p < 0.001$).

Baseline BHB concentrations were not significantly different between conditions and remained stable over time in the CHO condition (Figure 10). A significant supplement and time interaction was observed ($p < 0.001$). Both the MCT and MCT+CHO conditions showed significant increases across all intervals. By 30 minutes, BHB was significantly higher in the

MCT and MCT+CHO conditions than in the CHO condition ($p < 0.001$). From 60 minutes onward, all conditions differed significantly ($p < 0.001$), with the MCT condition eliciting the highest concentrations (1.02 ± 0.32 mmol·L^{-1}), followed by MCT+CHO (0.81 ± 0.25 mmol·L^{-1}), while CHO remained the lowest (0.13 ± 0.04 mmol·L^{-1}).

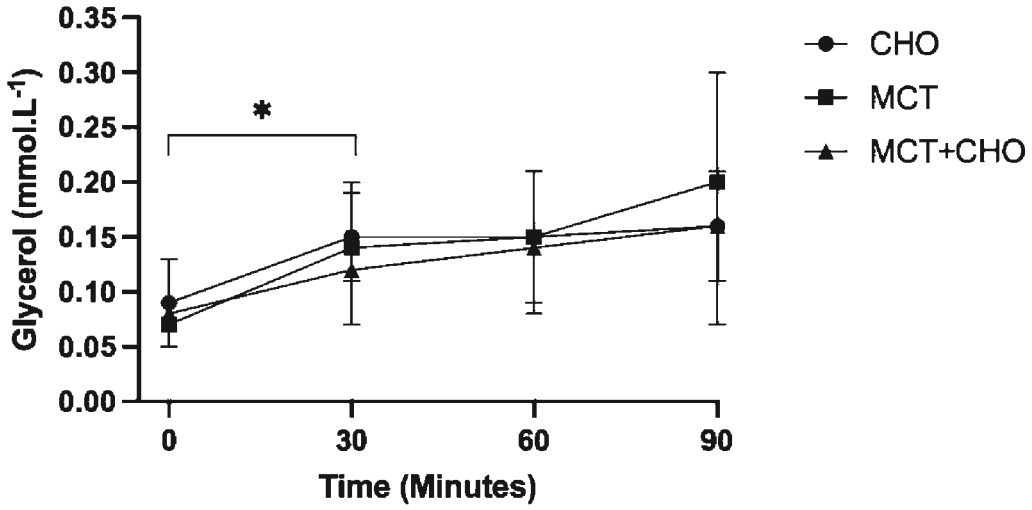


Figure 8. Mean serum glycerol concentrations for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. * Significant differences between baseline and 30 minutes ($p < 0.001$). No significant differences were observed between consecutive intervals (30–60 and 60–90 minutes).

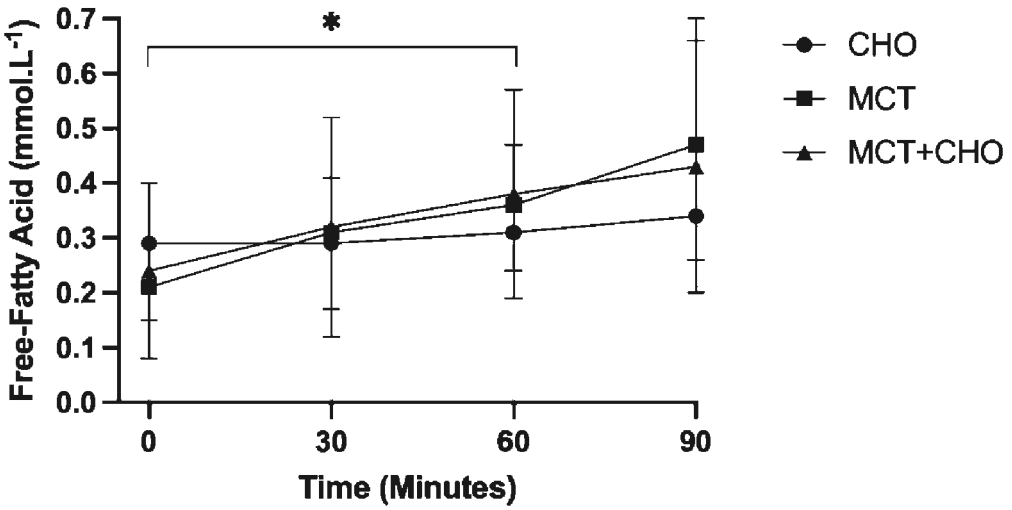


Figure 9. Mean serum FFA concentrations for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between baseline and 60 minutes ($p < 0.001$).

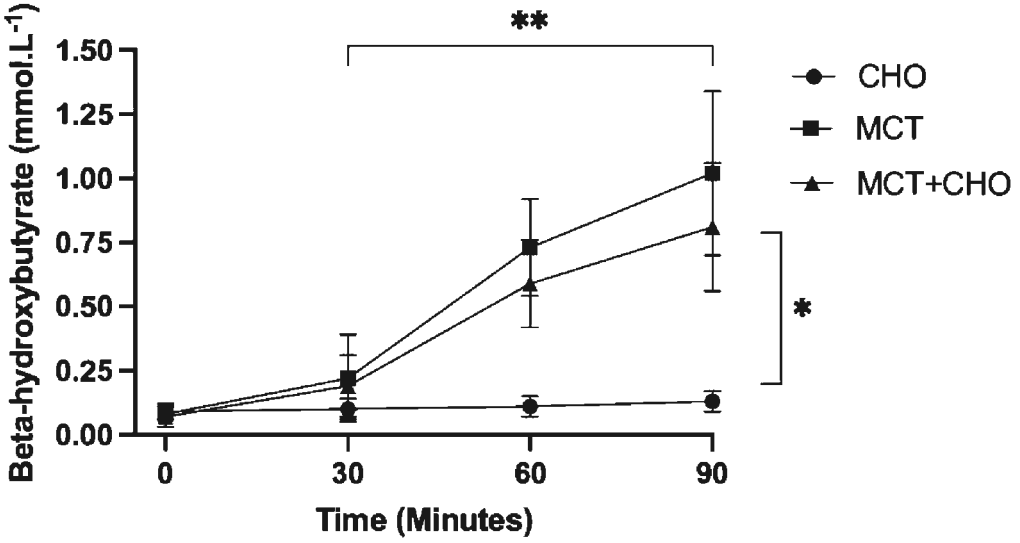


Figure 10. Mean serum β-hydroxybutyrate concentrations for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between MCT compared to the MCT+CHO and CHO conditions ($p < 0.001$). **Significant differences between 30 minutes and 90 minutes for MCT+CHO and MCT conditions ($p < 0.001$).

4.4.9.2 Plasma Glucose and Serum Lactate

The plasma glucose concentration, depicted in Figure 11, varied over time and between the supplement conditions ($p < 0.001$). Notably, stable euglycemic glucose concentrations were maintained in all three supplement conditions (4.9-5.6 mmol.L^{-1}). The MCT condition (5.1 ± 0.7 mmol.L^{-1}) had significantly lower mean concentrations during the 90-minute run than the CHO (5.8 ± 0.7 mmol.L^{-1}) ($p < 0.001$) and MCT+CHO conditions (5.56 ± 0.97 mmol.L^{-1}) ($p = 0.003$). However, no significant differences were found between the CHO and MCT+CHO conditions ($p = 0.173$). Post-hoc analysis indicated that glucose concentrations gradually increased over time from baseline until the end of the 90-minute run ($p < 0.001$). Notably, mean glucose concentrations across all the supplement conditions increased significantly within the first 30 minutes of exercise (from 4.9 to 5.6 mmol.L^{-1}) ($p < 0.001$), after which concentrations stabilized.

Serum lactate concentrations did not differ significantly between conditions ($p = 0.58$), as presented in Figure 12. Concentrations increased in the first 30 minutes of exercise, before significantly decreasing as exercise continued until the 90-minute mark in all three conditions ($p < 0.001$).

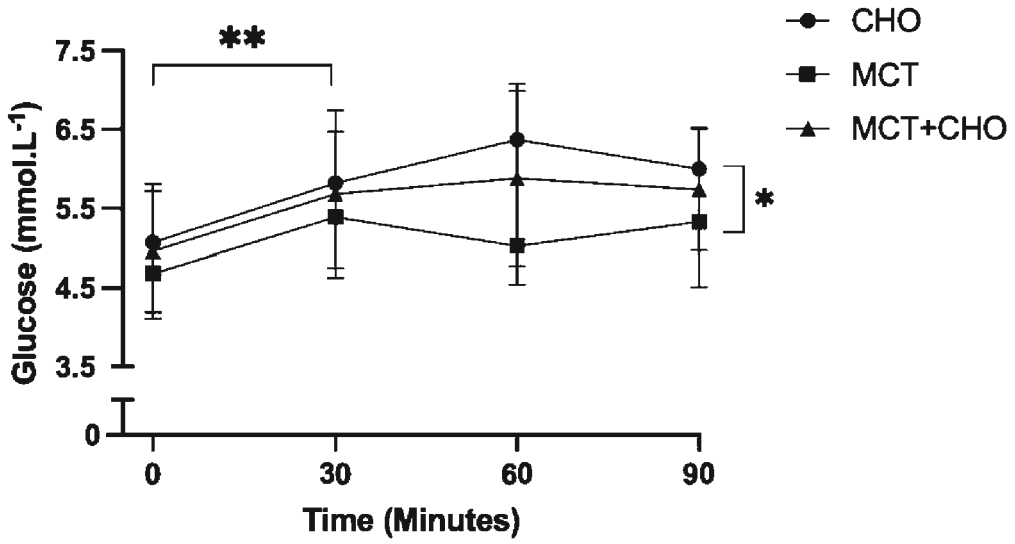


Figure 11. Mean plasma glucose concentrations for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean

± SD. *Significant differences between the MCT condition and the CHO and MCT+CHO conditions ($p < 0.05$). **Significant differences between baseline and 30 minutes ($p < 0.001$).

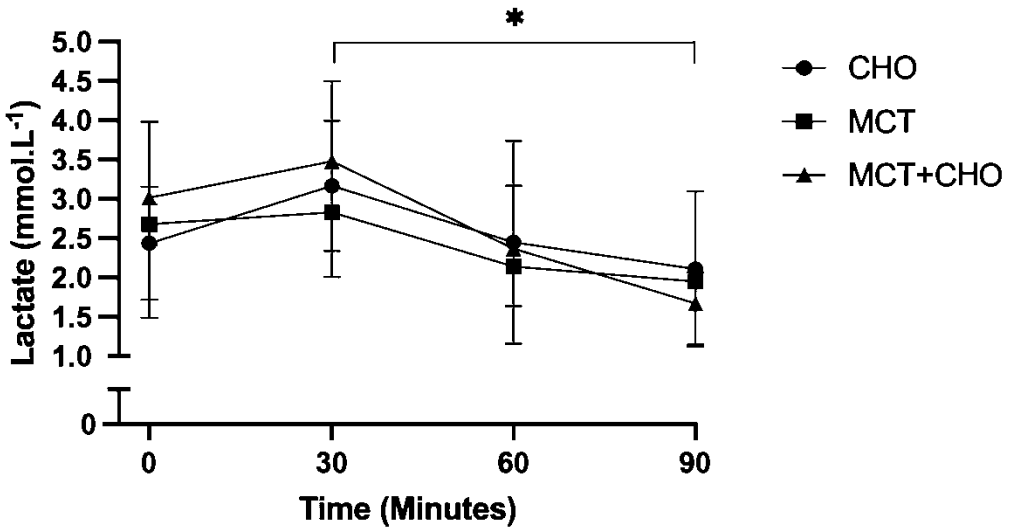


Figure 12. Mean serum lactate concentrations for CHO, MCT+CHO, and MCT supplement conditions during the 90-minute run at 75% Peak Treadmill Running Speed. Values are Mean ± SD. *Significant differences between 30 and 90 minutes ($p < 0.001$)

4.4.10 5km Time-Trials

The HR, RPE, and GI tract discomfort results are summarised in Table 9.

Table 9. The Heart Rate, Ratings of Perceived Exertion, and GI Tract Discomfort during the 5km TT.

Group	HR (bpm)	RPE	GI Tract
CHO	172 ± 11.9 [a]	8.3 ± 1.02 [a]	0 ± 0 [a]
MCT	172.8 ± 12.5 [a]	8.46 ± 0.91 [a]	0.5 ± 1.5 [a]
CHO + MCT	170.7 ± 14.4 [a]	8.18 ± 1.1 [a]	0.2 ± 0.5 [a]

Values are presented as mean ± SD for heart rate (HR), rating of perceived exertion (RPE), and gastrointestinal (GI) tract symptoms and are averaged over time across the 5km TT for each supplement condition. Superscript letters denote pairwise differences between conditions ($p < 0.05$). Conditions sharing a common superscript letter are not significantly different. Values were average over time.

4.4.11 Heart rate and RPE

Post-hoc analyses revealed that HR and RPE significantly increased over a distance of 1-3 km ($p < 0.0001$). However, after the 3 km point, neither significantly differed between consecutive km, suggesting both stabilized. Differences between conditions were not significant (Table 9).

4.4.12 GI Tract

GI could not be modelled-as most responses were zero (100% of responses for CHO; 90% of responses for MCT+CHO, and 88% of responses for MCT) (Table 9).

4.4.13 Time-Trial Times

There were no significant differences between conditions ($p = 0.17$). However, the fastest mean time was observed in the MCT+CHO condition, and the slowest was observed in the MCT condition (time to completion was 21:45 vs. 22:12 and 22:54 (min:sec), respectively) (Figure 13). Among the 10 participants, the fastest 5 km TT performances were recorded in five participants from the MCT+CHO condition, followed by three participants in the CHO condition. Of these five, three participants completed the MCT+CHO trial in their final testing session, while two achieved their fastest time while supplementing with MCT+CHO, neither of which was in their last testing session. Given that the testing order was randomised, and the best performances were not exclusively clustered in the final testing session, it appears unlikely that order effects explain the observed pattern. Two participants were unable to complete the 5 km TT in the MCT condition due to gastrointestinal discomfort. These trials were excluded from the performance analysis, as the small sample size did not allow for reliable imputation.

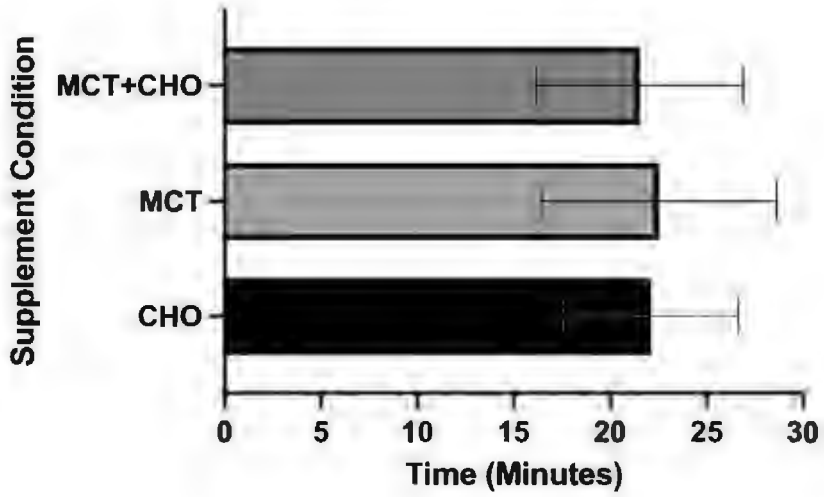


Figure 13. Mean final time (min:sec) for the CHO, MCT+CHO, and MCT supplement conditions during the 5 km TT. Values are Mean ± SD.

4.5 Discussion

The results of this study show that the MCT+CHO combination produced the lowest HR and RPE across all three supplement conditions during the 90-minute steady-state run. Moreover, five of the ten participants achieved their fastest mean time in the time trial when consuming MCT+CHO, compared to CHO or MCT alone. However, with a p-value of 0.17, no statistically significant differences in performance were observed between the three conditions.

Improved TT performances were seen by Van Zyl, et al [28] during a randomized cross-over study conducted on six endurance cyclists, in which the fastest TT times were achieved when MCT+CHO was ingested, compared to CHO or MCT alone. In the study by Van Zyl et al [28], participants consumed 400 ml of MCT (4.3%), CHO (10%), or a combination of MCT+CHO (4.3% + 10%) before exercise, followed by 100 ml every 10 minutes during exercise. This supplementation strategy is comparable to that used in the present study but featured more frequent ingestion intervals (every 10 minutes vs. every 15 minutes). Additionally, the Van Zyl et al [28] study implemented a longer time trial (120 minutes), resulting in a higher total MCT intake of 86g. Similarly, a 1998 study conducted by Jeukendrup, et al [131] on endurance cyclists tested the effects of MCT (85g), or CHO (150g), or MCT (85g) + CHO (150g), the results of which showed that the fastest TT times were observed in the MCT+CHO condition compared to the MCT condition [131]; however, these results were also not significant, which is similar to the results of this experimental trial. To the end, the Van Zyl [28] study is a clear outlier, as the

only study showing significant improvement in exercise performance when supplementing with MCT+CHO when compared to CHO.

Although not observed in this study, performance variations across CHO, MCT, and MCT+CHO conditions may result from several underlying factors. A plausible explanation for faster TT times when ingesting MCT+CHO is the likely accelerated rate of gastric emptying, as the combination of MCT and CHO appears to facilitate more rapid emptying [58]. This can be seen in the work by Beckers, et al [175], where nine male volunteers took part in four gastric emptying trials using liquid equicaloric mixtures of CHO and MCT. Gastric emptying was assessed at rest and over 90 minutes using a modified double-sampling method. The data analysis showed that MCT drinks emptied faster than the CHO only drinks. The authors attributed these results to MCT's unique properties, such as higher water solubility and faster absorption in the small intestine, which may reduce the inhibitory duodenal-gastric feedback typically associated with fats. This rapid uptake limits the presence of free fatty acids in the duodenum, weakening the feedback response that would otherwise slow gastric emptying [175]. Furthermore, Jeukendrup, et al [15], measured MCT oxidation in eight male triathletes cycling at 57% VO_2max for two hours. The study found that MCT oxidation was higher in the MCT+CHO condition compared to the MCT condition, suggesting that the combination of MCT and CHO facilitates faster substrate entry into muscle cells during exercise. This effect was attributed to an increase in gastric emptying.

The mechanisms underlying BHB production were discussed in Chapter 3, in which the expected rise in BHB concentrations with MCT ingestion was elucidated; this was observed in both the MCT and MCT+CHO conditions in the current study. As noted in the same section (Chapter 3), the unchanged BHB concentrations in the CHO condition are likely due to CHO intake suppressing ketone production. The findings of the current study are comparable to the findings of Jeukendrup, et al [131] and Goedecke, et al [168] where BHB concentrations increased in all conditions receiving MCT supplementation; however, the most rapid rise was observed exclusively in the MCT+CHO conditions in both studies. Both authors attributed this to the accelerated rate of gastric emptying in these conditions, further supporting that the co-ingestion of MCT and CHO facilitated a faster emptying of MCT from the gut. This, in turn, likely promoted a more rapid production of ketones, contributing to the elevated BHB concentrations. However, the current study did not observe the same pattern, as BHB concentrations did not differ significantly between the MCT and MCT+CHO conditions during the first 60 minutes of exercise. In the present study, BHB concentrations were highest in the MCT condition, while

values in the MCT+CHO condition were lower, consistent with the suppressive effect of carbohydrate on hepatic ketogenesis [7,104]. This contrasts with the findings of Jeukendrup, et al [15], and Goedecke, et al[168], where the combination of MCT and CHO resulted in higher BHB concentrations than CHO alone. Several factors may account for these discrepancies. First, MCT dosing protocols differed; earlier studies typically employed large bolus doses of 25-30 g, which may have exceeded immediate hepatic oxidative capacity, leading to measurable ketone production even in the presence of CHO [15]. In contrast, the present study provided MCT in smaller, distributed amounts, enabling CHO availability to exert a more pronounced inhibitory effect on ketogenesis. Second, participant characteristics likely played a role, as the highly trained cyclists in the Jeukendrup and Goedecke studies would have exhibited faster glycogen turnover and CHO oxidation rates, potentially blunting the inhibitory impact of exogenous CHO. Third, differences in sampling windows may also explain the variation, since BHB concentrations can peak later during prolonged exercise and may not always align with the measurement points across studies [162]. Collectively, these findings suggest that while CHO ingestion generally suppresses ketogenesis, the magnitude of suppression is influenced by the dose and timing of MCT intake, the metabolic characteristics of the participants, and the design of the measurement protocol.

The inclusion of a 90-minute steady-state run before the 5 km time trial is an important contextual factor in this study. Prolonged exercise at ~70–75% peak treadmill speed is sufficient to reduce muscle glycogen availability and increase reliance on hepatic glucose output and circulating substrates [141]. This creates a physiological context in which MCT supplementation could, in theory, influence substrate use through rapid hepatic oxidation of MCFA or modest ketone production [128]. However, the presence of CHO co-ingestion suppresses ketogenesis [131,168], and the subsequent 5 km time trial is a high-intensity effort dominated by CHO oxidation [202]. Consequently, even if MCT altered circulating substrate profiles during the preload, these substrates were unlikely to make a meaningful contribution to energy supply during the TT. This helps to explain why, in line with most previous literature, MCT containing supplementation did not significantly affect the TT performance.

As the CHO oxidation rates were similar in both the CHO and MCT+CHO trials, it is unlikely that the combination of MCT and CHO resulted in glycogen sparing. If glycogen sparing had occurred, one would expect a reduction in CHO oxidation when MCT was provided. Interestingly, a reduction in CHO oxidation was observed in the MCT condition, suggesting that MCT supplementation, in the absence of CHO, may spare CHO utilization during steady-

state exercise. The potential CHO-sparing effect of MCT is most likely attributable to reduced muscle glycogen utilisation in the presence of elevated plasma FFA, as has been observed[141]. While euglycemia was maintained in the MCT condition, this should be viewed as a consequence of substrate balance during exercise rather than the direct mechanism by which CHO sparing occurred. Furthermore, lower lactate concentrations observed in the MCT condition indicate a reduced dependence on CHO oxidation in this condition [176–178] when compared to the CHO condition.

Although no change in performance was seen in the MCT+CHO condition, a reduction in GI tract discomfort was noted when ingesting CHO compared to MCT alone. GI tract discomfort is a common side effect of endurance exercise, often worsened by ingesting food immediately before or during exercise [97,189]. Runners are commonly affected by gut discomfort due to the large amounts of gut movement and vertical oscillations during exercise, which is significantly more than in cyclists, as postulated by Peters, et al [144]. GI tract discomfort is often worsened when supplementing with MCT, as discussed in the scoping review of Chapter 3. Such discomfort following MCT ingestion has been noted in both running and cycling trials [129,132,131,168]. The 2001 study conducted by Misell, et al [106], tested the effects of chronically supplementing runners with > 30 $g.hr^{-1}$ MCT, resulting in GI discomfort in 100% of the participants. However, fewer participants experienced gut discomfort when supplementing with < 30 $g.hr^{-1}$ [129]. The MCT supplements administered in this trial did not exceed 30 $g \cdot h^{-1}$ (totalling 32.2 g over the 90-minute run). Although the MCT condition produced the highest GI discomfort rating, the mean score was only 2/5, which is not considered severe. However, two of the 10 participants in the MCT condition could not complete the 5km TT and voluntarily ended the testing early due to severe discomfort and nausea. This 20% effect would indicate that the severity of MCT-induced discomfort is individualized. Fewer complaints were evident in the MCT+CHO condition (mean rating of 1/5). Although the amount of MCT was the same in the MCT and MCT+CHO supplements, adding CHO to MCT could have reduced GI tract discomfort. This is likely because of the regular use of CHO by the participants, as 95% self-reported using CHO supplementation during races, indicating a level of familiarity with using CHO during high-intensity exercise. Evidence [133] discussed in section 2.3 shows that regular intake of CHO supplements improves gastric emptying, reducing the feeling of fullness and symptoms such as discomfort. This is likely due to the increase in SGLT1 transporters, which increased the absorption of CHO and emptying of the gut. Gut familiarity was observed in the study by Misel, et al [132] where GI tract discomfort was reduced over 14 days of chronic MCT

ingestion, indicating that with regular training, the gut can become accustomed to supplementation. Therefore, runners should try new supplements, such as MCT, during training runs to best prepare for race days.

The MCT+CHO condition was associated with the least favourable running economy relative to the CHO and MCT conditions. Running economy or VO_2 ($ml.kg^{-1}.min^{-1}$) at a given work rate is likely better in a well-trained athlete than a recreational runner, who generally requires less oxygen at the same speed of [189,203]. When comparing the three supplement conditions, the highest VO_2 was seen in the MCT+CHO condition (44,7 $ml.kg^{-1}.min^{-1}$), compared to the CHO condition (42,2 $ml.kg^{-1}.min^{-1}$). Although the difference in VO_2 appears small (2,5 $ml.kg^{-1}.min^{-1}$) it translates to a substantial difference in the $\%VO_2max$. Specifically, with a mean VO_2max of 63,3 $ml.kg^{-1}.min^{-1}$, the difference in submaximal oxygen uptake is a difference of 70,6% VO_2max vs 66,7% VO_2max. In running terms, this is a "massive" difference in the fractional utilisation of VO_2max at the same submaximal speed. The implication for performance over a distance such as a marathon is important since a well-trained athlete can be expected to run a marathon at approximately 85% VO_2max. One proposed benefit of maintaining high CHO oxidation during a marathon is that it allows a lower relative $\%VO_2max$ compared with relying more heavily on fat as a fuel source [189]. On the other hand, the increased VO_2 seen in this condition could be associated with the higher cost of metabolizing fats and the need for increased oxygen uptake for beta-oxidation [204]. Despite the worst economy in the MCT+CHO, this condition experienced the lowest HR and RPE compared to the CHO and MCT conditions. While the CHO+MCT condition showed the lowest mean HR and RPE values, the differences were small (4 bpm and 0.1 RPE units) and within the expected biological variation for endurance exercise responses [205]. It is unlikely that substrate oxidation directly reduced cardiovascular strain, since fat oxidation has a higher oxygen cost per unit of ATP compared with CHO oxidation [126,206]. Instead, these small differences may be more plausibly explained by secondary mechanisms, such as improved GI comfort reducing sympathetic activation and perceived exertion, as has been suggested in studies linking GI distress with elevated RPE during endurance exercise [137]. Therefore, the observed reductions in HR and RPE in the CHO+MCT condition are best interpreted as modest and likely attributable to improved tolerance, rather than a direct cardiovascular unloading effect of substrate metabolism. A further assumption is that the stable plasma glucose concentrations from CHO intake may have mitigated central fatigue by maintaining brain glucose availability, thereby reducing perceived

exertion. However, if this were the case, lower HR and RPE would have been observed in all CHO containing conditions, and not only the MCT+CHO condition.

Following a HF diet or ingesting HF supplementation, such as MCT, often results in increased fat oxidation [114], as discussed in section 2.2.2.1. Noakes, et al [114] discussed the intricacies of fat oxidation recently in a 2023 commentary paper on substrate used at different intensities when following either HF or HC diets. The evidence reviewed showed total fat oxidation rates in HF diet conditions between 1.2-1.6 g.min^{-1} when exercising at 70% VO_2max – an intensity when fat oxidation should be minimal (typical fat oxidation of 0.5 g.min^{-1}) [114]. To this end, Burke, et al [44] observed fat oxidation increased from 0.5-1.4 g.min^{-1} after following a HF diet for only 5 days. In contrast, participants in our study consumed a moderate CHO and low fat diet comprising 46% CHO and 33% fat, and consequently, peak fat oxidation during the 90-minute run remained below 1 g.min^{-1}, as expected. However, fat oxidation in the MCT condition (0.5 g.min^{-1}) was significantly higher than the CHO condition (0.33 g.min^{-1}), suggesting MCT can increase fat oxidation without a HF diet. The same mean fat oxidation was observed in the study by Goedecke, et al, [169] during two hours of cycling at 55%, where participants reached a mean rate of 0.5 g.min^{-1} in the MCT condition. It is important to note that the fat oxidation values reported in this study (g·min^{-1}) represent absolute rates and not the fractional contribution. Fat oxidation can be expressed either as the fractional contribution to total energy expenditure (percentage of fuel mix) or as the absolute oxidation rate (g·min^{-1}), and while the fractional contribution typically decreases with higher exercise intensity, absolute fat oxidation may continue to rise until a moderate–high intensity is reached before declining [141,142].

The RER, as presented in Chapter 2, section 2.2.2, indicates the relative amount of CHO and fat oxidation during exercise. Despite the same intensity used for each 90-minute run, not unexpectedly, higher RER values were observed in the CHO condition (0.95) compared to the MCT+CHO (0.93) and MCT condition (0.90). Although high-intensity exercise typically relies on CHO oxidation, lower RER values observed in the MCT condition suggest reduced CHO dependence and increased fat utilization compared to the CHO condition. The observed condition effects on $\dot{V}O_2$ and RER are consistent with substrate stoichiometry: CHO oxidation produces more CO_2 per O_2 (higher RER) and requires less O_2 per unit energy, whereas fat oxidation requires more O_2 and lowers RER [126,207]. Hence, the CHO trial's high RER and relatively low $\dot{V}O_2$, and the MCT trials' lower RER and higher $\dot{V}O_2$, are physiologically plausible.

Although the serum glycerol concentrations increased over time within all the conditions from baseline to the end of the 90-minute run, concentrations were highest in the MCT trial in the final hour compared to CHO. The lower concentrations in the CHO condition are expected, as the consumption of CHO typically attenuates lipolysis [58]. Similar glycerol concentration patterns were seen in the study by Jeukendrup, et al [15], where concentrations did not differ between conditions, but rather increased over time within all three supplement conditions during a 180-minute cycle at 57% VO_2max (MCT, CHO, or MCT+CHO). As with serum glycerol concentrations, no significant difference was seen in the FFA concentrations between conditions. However, this does not indicate that metabolized MCT were not oxidized or did not enter the systemic circulation. Previous research conducted by Massicotte, et al [207] which measured the oxidation of MCT using blood isotopes, reported that 54% of ingested MCT were oxidized within two hours of exercise, without observing a difference in FFA concentrations when compared to the CHO condition. The authors associated this with rapid oxidation of MCT, which reduces accumulation in the blood, therefore not increasing blood FFA.

4.6 Conclusion

The findings of this study show that although the use of MCT paired with CHO may reduce steady-state exercise capacity if the increase in submaximal VO_2 is considered, the combination nevertheless resulted in reduced HR and RPE compared to MCT alone. Furthermore, the use of MCT, both alone and in combination with CHO, maintained euglycemic plasma glucose concentrations during 90 minutes of running. When consumed alone, MCT demonstrated enhanced fat metabolism and a likely CHO-sparing effect during steady-state exercise, although this did not translate into performance improvements. As no habitual diet change was feasible in this study, the use of a HF diet could not be investigated. Future research should investigate the effects of combining MCT and CHO under different diet conditions.

4.7 Strengths and Limitations

The randomized crossover design provides a robust framework for comparing the effects of different supplements, reducing variability between participants. The thorough methodology of the study mimics real-life endurance events, making findings applicable to endurance runners. Additionally, the methodology utilizes current supplementation best practices. Importantly, the study was conducted on endurance runners, a population where evidence on MCT is currently limited, addressing a significant gap in the literature.

Whilst the inclusion of both male and female participants provides a further understanding of the effects across sexes, it also presents a limitation of this study. Although both male and female participants were included, the overall sample size (n = 10) was too small to allow for meaningful sex-specific analyses. The power analysis was based on the primary outcomes of the study and did not account for subgroup comparisons by sex. Following the scoping review, it became clear that there is a relative scarcity of research on female athletes in this area, and this highlighted the importance of investigating potential sex-specific responses to MCT supplementation. Unfortunately, with the small sample size available, the study was not powered to address these differences. Future research with larger cohorts and sufficient power to stratify by sex and menstrual cycle phase is needed to address this important gap.

An additional limitation of the small sample size was the absence of a comparison between HF and HC diets. Furthermore, muscle glycogen was not directly measured, making accurate evaluation of substrate utilization and the full metabolic impact of the interventions difficult. To directly test whether an intervention spares muscle glycogen would require repeated muscle biopsies pre- and post-exercise (and ideally during exercise), combined with tracer methods to partition exogenous versus endogenous CHO oxidation (e.g., 13C-labelled glucose) and measures of hepatic glucose output. Without these direct measures, interpretation of glycogen sparing from whole-body oxidation data alone is limited. Additionally, participants' habitual diets and pre-test food intake were self-reported, introducing potential inaccuracies in dietary tracking that could have influenced the study outcomes.

An additional limitation of this study is that steady-state running intensity was set at 75% of each participant’s peak treadmill speed. While this method provides a pragmatic and reproducible approach, it does not ensure that participants were exercising relative to the same physiological threshold. For example, the same percentage of peak speed may place one participant below their lactate threshold or critical speed, while another may be above it. Anchoring intensity to physiological thresholds, such as lactate threshold, ventilatory threshold, or critical speed, would provide a more precise method of standardising relative intensity across individuals and should be considered in future research.

A limitation of the present study is that the precise menstrual cycle phase for female participants was not measured. Ovarian hormones, such as progesterone, alter multiple aspects of substrate metabolism and can influence whole-body fuel selection during exercise. On the other hand, oestrogen generally promotes greater lipid availability and oxidation and a relative sparing of

CHO [208]. Experimental studies have reported phase-dependent differences in glucose kinetics, substrate oxidation, and, in some protocols, exercise performance, although the literature is mixed and effects are protocol dependent. Campbell, et al, [209] showed that substrate metabolism and exercise performance can differ between cycle phases; however, acute glucose ingestion during exercise attenuated those differences [209]. Conversely, more recent studies indicate that the influence of menstrual phase on some outcomes, for example, peak fat oxidation in graded tests, may be small or inconsistent between protocols and cohorts, highlighting heterogeneity in the literature [210] . However, the experimental design required that all participants complete two days of CHO loading, consume a standardised CHO-rich breakfast before each trial, and ingest CHO during exercise. Although these procedures were implemented to address the primary aims of the study, they also likely reduced the magnitude of any cycle-related differences in substrate availability and utilisation, as CHO feeding has been shown to attenuate some of the hormonal effects across phases [209]. Nevertheless, because the cycle phase was not measured, residual variability cannot be excluded, and future studies should consider incorporating hormonal verification or cycle-phase standardisation to improve internal validity**.**

4.8 Acknowledgements

The consultation of a professional statistician was utilized for the statistical analyses.

Chapter Five: Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO and Fat-loading strategies used in Preparation for a Marathon.

Chapter Introduction

The macronutrient intake collected from the 3-day food logs of the participants in Chapter 4 indicated none of the participants followed a diet consisting of ± 56% CHO, which falls below current recommendations for endurance runners (> 60% CHO) [184,185]. Another notable observation of the experimental trial was the lack of willingness to partake in a HF diet (> 70% daily intake from fats) and the inability to recruit participants, which was surprising given the popularity and success of the HF diet movement. Thus, this Chapter aims to further understand the dietary habits of marathon runners in the month, days, and immediately before a marathon race.

Abstract

Athletic performance is optimized through the marginal gains of targeted nutritional strategies. Due to the lack of current data, this study aimed to describe the dietary habits of South African marathon runners in the month and days leading up to a marathon race. **Methods:** In this observational descriptive repeated cross-sectional study, 197 South African marathon runners (consisting of different cohorts from 2014 and 2024) were recruited, and their dietary habits during marathon training were assessed and compared between the years. A Food Frequency Questionnaire (FFQ) estimated each runner's macronutrient [carbohydrate (CHO), protein, and fat] intake in grams during the month leading up to a marathon. Energy expenditure was estimated by summing basal metabolic rate (BMR), thermic effect of food (TEF), and exercise activity, each calculated using predictive equations. A questionnaire was used to collect information on the participants' self-reported CHO and, or fat-loading strategies used on the days immediately before a marathon. Importantly, the questionnaire and procedures for assessing dietary intake and energy expenditure were identical across both time points, allowing for direct comparison between cohorts. **Results:** The participants from 2014 and 2024 had a daily energy intake of 2373 (1779, 2992) KCal and 2282 (1849, 3335) KCal, and an expenditure of 2362 (2134, 2735) KCal and 2493 (2042, 2816) KCal, respectively. The macronutrient distribution for the 2014 and 2024 cohorts ranges between 46-52% CHO, 16-17% protein, and 29-34% fats fell within the Food and Nutrition Board of the Institutes of

Medicine (IOM) acceptable macronutrient distribution range (AMDR). However, the absolute CHO intake (g.kg^{-1} value) fell below the recommended values for endurance athletes (> 5.kg^{-1}·day^{-1}). The results from 2014 to 2024 revealed that 59-63% of runners practiced CHO-loading before marathons; most commonly, 2-3 days before a marathon. However, only 30-60% perceived it as effective for enhancing performance (between 2014 to 2024). Although the overall sample was less likely to restrict fat intake in 2024 (30%) than in 2014 (58%), the largest decrease in fat restriction was seen in the male runners, which reduced from 64% to 3% from 2014 to 2024. From the overall sample from both cohorts, less than 6% of runners opted to fat load on the days before a race. **Conclusion:** The macronutrient intake of South African marathon runners is balanced (within the IOM AMDR), despite a comparatively lower absolute CHO intake. In addition, this study provides valuable insights into the CHO and fat-loading practices of marathon runners on the days prior to a race.

5.1 Introduction

Optimizing marathon running performance requires specific nutritional requirements. This is due to the high energy demands and prolonged duration of activity [187]. Olympic qualifying marathon runners report running 120-160km (females) and 180-220 km (males) per week, while competitive recreational runners cover distances ranging from 40-75km per week [211]. Whilst training, runners covering distances of 10-20km a day can typically expend ± 700 - 1400 Kilocalories (KCal) on running, depending on various factors, such as gender and training experience [211]. Furthermore, runners expend approximately 2900 KCal to complete a 42.2km marathon race [56]. Given the high energy demands of marathon running, ensuring sufficient calorie intake is essential for optimal performance. Runners should ensure they meet a balance between energy consumption and expenditure, particularly during intense training periods or leading up to a race when training duration, frequency, or intensity are increased.

Although marathon runners' diets vary greatly [36], the evidence most commonly supports a balanced approach to macronutrient intake [35]. Furthermore, numerous nutritional guidelines and acceptable macronutrient distribution ranges (AMDR) have been proposed in the literature [31–34] for optimizing training.

CHO are particularly important in fuelling muscles during exercise, with recommendations ranging between 3-12 g.kg^{-1}.day^{-1}, depending on an individual's activity level and energy demands. 3-5 g.kg^{-1}.day^{-1} for lower activity levels, and athletes training for 1-3 hours daily should consume 6-10 g.kg^{-1}.day^{-1}, while 8-12 g.kg^{-1}.d^{-1} is recommended for those training 4-5

hours [212,213], as presented in section 2.2.1.3. A high CHO intake (defined as a diet comprising > 60% of daily intake from CHO) [184] supports adequate muscle and liver glycogen synthesis to support performance [214]. Conversely, low glycogen stores are associated with the onset of fatigue and reduced performance [215,216]. Despite this, marathon runners often consume insufficient CHO, below 8 $g.kg^{-1}$ per day [214,217].

Between 2014 and 2019, a low-carbohydrate high-fat (LCHF) diet, commonly referred to as the 'keto diet' gained popularity due to the proclamation of various health benefits and potential advantages for endurance performance [218–220]. Burke, et al [5] classified a LCHF diet as one consisting of 10% CHO and 70% fat. The LCHF diet potentially enhances fat metabolism by favourably utilizing intramuscular fat [221], and sparing muscle and liver glycogen [218,219]. However, the potential benefits of a LCHF diet on endurance performance remain inconclusive [212,221,222], as discussed in Chapter 2.

In addition to habitual CHO intake recommendations, marathon runners are commonly advised to CHO-load on the days before a race. As discussed in Chapter 2, current recommendations for CHO-loading vary based on the level of physical activity, typically ranging between 8-12 $g.kg^{-1}.day^{-1}$. Despite the recommendations, marathon runners regularly fail to meet their energy and CHO needs in their habitual diets, or whilst CHO-loading [36,211,223,224].

Evidence from 2016 [223] revealed that 27% of 422 runners followed a diet comprising 60% CHO, 20% fat, and 20% protein [223]. Only 6% of these runners were following a HF diet, consisting of 60% fat, 10% CHO, and 30% protein [223]. Additionally, in the same sample of runners, only 64% of them CHO-loaded on the days before racing [223]. The most recent literature (2020) collected on marathon runners' habitual intake shows CHO comprising 48%, with 21% protein, and 34% fat [225]. Research conducted on South African ultra-marathon runners also showed an increase in CHO intake on the days leading up to a race, with participants reporting increased CHO intake from 50% CHO during training, to 57% CHO before races [36]. Despite this 7% increase, it falls below CHO-loading suggestions of > 60% daily intake.

Despite Peters, et al [226] describing the dietary intake of South African 90-km ultradistance runners, there is currently no evidence regarding the habitual diets of South African 42.2-km marathon runners [227,228]. Therefore, this study aimed to comprehensively describe the habitual diet of South African marathon runners, including their total energy intake, exercise-related energy expenditure, and resultant energy balance. Additionally, it sought to analyse their macronutrient distribution to understand dietary habits and their alignment with endurance

performance requirements [229]. Additionally, this investigation aimed to further understand the CHO and fat-loading (a term used to describe an increase in fat intake on the days before an event [44], similar to CHO-loading) strategies used on the days before a race. Finally, this study aimed to compare the dietary practices of marathon runners between two cohorts from 2014 and 2025, to identify if practices have changed over the last decade.

5.2 Methodology

This observational descriptive repeated cross-sectional study compared data from South African marathon runners recorded in 2014 with newly collected data from a 2024 cohort to examine changes in dietary habits over the past decade. Considering that 159 participants' data were collected in 2014, a sample size calculation using a two-tailed statistical test for the difference between two independent means (Cohen's $d = 0.5$, $\alpha = 0.05$, power = 0.8) determined that 64 participants were required for the 2024 analysis to achieve a medium effect size. The study adhered to the Declaration of Helsinki (2013) principles and was approved by the University of Cape Town's Faculty of Health Sciences' Human Research Ethics Committee (HREC 513/2022), and all participants completed consent forms before taking part in the study.

5.2.1 Participants

Eligible participants recruited for this study (in both 2014 and 2024) were South African runners, males or females, who had completed at least one marathon (42.2 km) in the past two years. Participants were apparently healthy, literate in English, and free of chronic diseases, injuries, or food allergies/intolerances at the time of data collection.

5.2.2 Study Procedures and Data Collection

For the 2014 participants, recruitment took place at various running events and races or running clubs, where on-site field workers assisted with participants' queries. Participants who volunteered to partake in the study were given a Participant Information Sheet. If all inclusion/exclusion criteria were met, participants were given an Informed Consent Form to complete. All 2014 data was collected by a BSc Med Hons in Dietetics final year students at UCT. This data was registered as a database with HREC (R028/2024) under A/Prof Harbron.

Recruitment of the 2024 participants took place at various running events, races, or running clubs. Additionally, an email advertisement was sent to running clubs around South Africa (Appendix G). Participants willing to participate in the study were given a consent form (Appendix H) and a Participant Information sheet (Appendix I). Once consent was given,

participants received the Participant Instructions (Appendix J) on how to complete the provided Food Frequency Questionnaire (FFQ) (Appendix K), as well as the Participant Health and Lifestyle Questionnaire (Appendix L).

The data capture procedures, methodology, energy expenditure calculations, and dietary measurements were identical for both the 2014 and 2024 participant cohorts, thereby ensuring direct comparability between the two datasets. Dietary intake, training routines, and socio-demographic details were assessed. Participants were also requested to report on their sex, age, height, weight, running frequency, running distance, and running category (elite competitive, recreational competitive, or recreational). The FFQ was adapted from an FFQ template (Steyn & Senekal, 2004), had 124-line items, and a recall period of the past month. Daily intake, in gram amounts, was calculated for each line item using the recorded frequency and quantity. For portion size estimation, standard portion sizes in household measures and symbols reflecting amorphic portion sizes were included in the FFQ and were converted into gram amounts using the South African Food Quantities Manual [170]. The South African Food Composition database [171] was used to calculate daily energy and macronutrient intake. Of the 159 questionnaires collected from the 2014 participants, 27 were removed for incorrect completion of the FFQ. All the 2024 questionnaires were completed correctly, and therefore, none were excluded. Additionally, participants reporting implausible daily energy intakes (< 500 or > 5000 KCal) were excluded from dietary analysis (n = 8). However, all 159 (2014) and 65 (2024) participants adequately completed the Health and Lifestyle Questionnaires, which comprised information relating to the CHO and fat-loading strategies.

Daily energy expenditure was estimated from three components: basal metabolic rate (BMR), thermic effect of food (TEF), and exercise activity. Weight and height were reported, and BMI was calculated. BMR was calculated using the sex-specific Harris-Benedict equations based on weight, height, and age. TEF was estimated as 10% of BMR. Exercise energy expenditure was calculated by combining running-related energy expenditure (0.97 $KCal \cdot kg^{-1} \cdot km^{-1}$) and non-running activity data from the Participant Health and Lifestyle Questionnaire. Non-running activity was evaluated using the 2024 Adult Compendium of Physical Activities (Appendix M) [172], applying the formula:

$$0.0175 \times weight\ of\ participant\ (kg) \times$$

$$\Sigma\ [MET\ value \times hours\ of\ specific\ sport\ participation\ per\ week\ (hrs/week)] \times \frac{60}{7}.$$

5.2.3 Data and Statistical Analyses

The data were analysed using Statistical Package for the Social Sciences (SPSS) software program (version 29.0). Categorical data were described using counts and percentages (%), and when necessary, a chi-squared analysis and post hoc tests were conducted. Numerical variables were tested for normality using the Shapiro-Wilk test. Numerical data with a normal distribution were described using means and standard deviations (SD) or adjusted means and standard error (SE) when adjusting for covariates; otherwise, medians and interquartile ranges (IQRs) were used.

Depending on normality, Independent t-tests or Mann-Whitney U tests were used to compare 1) the sex, age, height, weight, BMI, running frequency and distance of the 2014 and 2024 conditions; 2) the estimated daily energy and macronutrient intake, energy expenditure and energy balance of males and females in 2014, and 3) the estimated daily energy and macronutrient intake, energy expenditure and energy balance of males, females, and the total sample from 2014 and 2024. An ANCOVA test was used, while controlling for age, to compare the estimated daily energy and macronutrient intake, energy expenditure, and energy balance of the males, females, and the overall sample between 2014 and 2024.

The estimated total daily energy intakes and expenditures of the male, female, and overall sample were compared using a paired *t*-test. A p-value < 0.05 was considered significant.

5.3 Results

5.3.1 Participant Characteristics

The general characteristics of the participants from 2014 and 2024 are presented in Table 10. The 2014 participants were significantly older than the 2024 participants ($p < 0.001$). Upon further analysis, only the ages of males in 2014 (n = 84) and 2024 (n = 35) were significantly different ($p < 0.001$), whereas the women's age did not differ ($p = 0.291$).

Table 10. General Characteristics of the 2014 and 2024 Groups.

	2014 (n = 132)	2024 (n = 65)	*p*-value
Age (yrs)	44 (36, 52)	36 (30.5, 46)	**<0.001**
Height (m)	1.72 ± 0.09	1.73 ± 0.10	0.483
Weight (kg)	70.19 ± 11.38	70.12 ± 14.65	0.973
BMI (kg/m^2)	23.3 (21.6, 25.4)	22.2 (20.6, 26.0)	0.363
Running Frequency ($d.wk^{-1}$)	4 (4, 5)	4 (3, 5)	0.853

Running Distance (km.wk^{-1})	55 (40, 68)	50 (40, 65)	0.475

Data are presented as mean ± SD or median (IQR) (n =197). BMI: body mass index, yrs: years, m: meters, kg: kilojoules, d.wk^{-1}: days per week, km.wk^{-1}: kilometres per week. Bold p-values indicate significance.

In both 2014 and 2024, the majority of the participants classified themselves as 'recreational and competitive' runners, whereas only 5% classified themselves as 'elite and competitive' runners (Figure 14). Self-identified runner classifications did not differ significantly between 2014 and 2024 (p = 0.833).

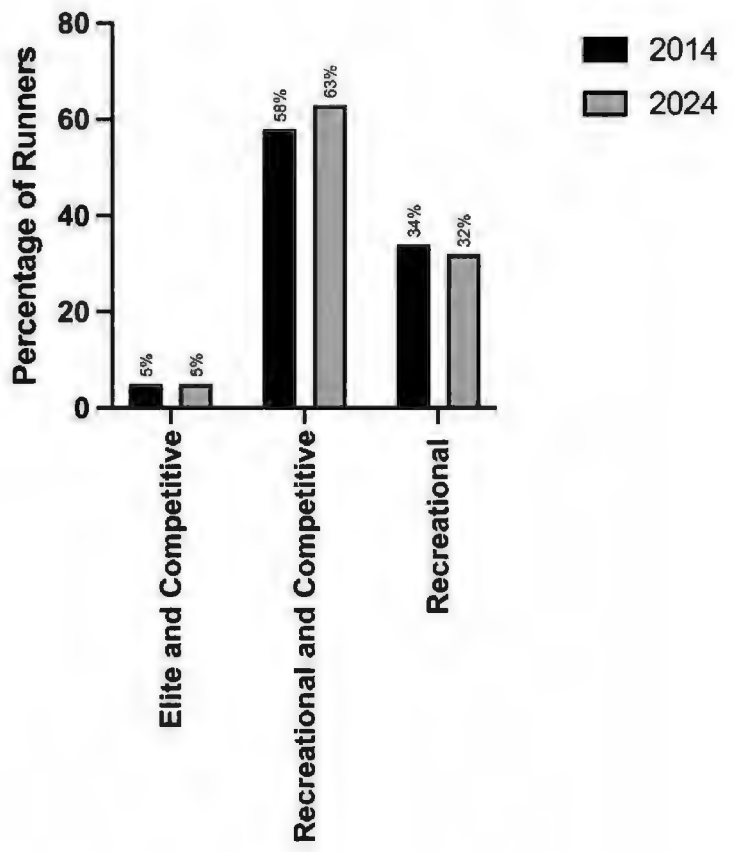


Figure 14. Self-identified runner classification between 2014 and 2024 participants (n = 224) (p = 0.833).

5.3.2 The 2014 Daily Energy and Macronutrient Intake and Energy Expenditure

Table 11 depicts the energy intake, expenditure, and energy balance of the males, females, and the overall sample from 2014. Despite the estimated total daily energy intake being similar across the males and the females, the females consumed significantly more protein per kg of body weight than the males (1.2 ± 0.5 g.kg^{-1}.d^{-1} vs 1.4 ± 0.7 g.kg^{-1}.day^{-1}; p = 0.043). Amongst all participants, CHO contributed the most to daily energy intake, followed by fats and protein.

The total daily energy expenditure, as well as all components used to estimate the daily energy expenditure of the males, were significantly higher in comparison to the females, except for the non-running-related energy expenditure, which showed no significant differences.

5.3.3 Comparison of the 2014 and 2024 Groups for Daily Energy and Macronutrient Intake, Energy Expenditure, and Energy Balance

There was no significant difference in total daily energy intake between 2014 and 2024 in the male, female, or overall sample (Table 12); however, in 2014, the males consumed more CHO than in 2024 (4.7 ± 0.2 g.kg^{-1}.d^{-1} and 3.4 ± 0.3 g.kg^{-1}.day^{-1}; $p = 0.012$). Additionally, the females and the overall sample consumed significantly more fats in 2024 than in 2014.

Although there was no statistically significant difference in the total daily energy expenditure of the overall sample between 2014 and 2024, the males had a significantly higher daily energy expenditure in 2024 (2820 ± 79 KCal.d^{-1}) than in 2014 (2609 ± 49 KCal.d^{-1}), despite accounting for age. Additionally, all components used to estimate the daily energy expenditure of the males were significantly higher in 2024 than in 2014, except for running and non-running-related energy expenditures, which showed no significant differences. No significant changes in energy expenditure or energy balance were observed in the female and overall sample over the decade; however, the male sample had a significant decrease in energy balance from 2014 to 2024 ($p = 0.039$), indicating that their energy expenditure increasingly exceeded their energy intake (Table 12).

Table 11. Participants' Average Estimated Daily Energy Intake and Expenditure, and Overall Daily Energy Balance.

	Males		Females		p-value	Overall	
	Mean ± SD or Median (IQR)	% of Total Daily Calories	Mean ± SD or Median (IQR)	% of Total Daily Calories		Mean ± SD or Median (IQR)	% of Total Daily Calories
Energy Intake	Males (n = 80)		Females (n = 46)			Overall (n = 126)	
Daily Energy Intake ($KCal.d^{-1}$)	2462 (1874, 3086)	100%	2324 (1522, 2820)	100%	0.146	2373 (1779, 2992)	100%
CHO							
$g.day^{-1}$	305 (241, 397)		294 (174, 349)		0.059	302 (230, 377)	
$g.kg^{-1}.day^{-1}$	4,0 (3.3, 5.3)		4.7 (2.6, 6.1)		0.627	4.2 (3.2, 5.8)	
$KCal.d^{-1}$	1219 (964, 1587)	53%	1177 (696, 1396)	50%	0.059	1209 (920, 1508)	52%
Protein							
$g.day^{-1}$	95 (75, 123)		89 (72, 129)		0.533	91 (74, 126)	
$g.kg^{-1}.day^{-1}$	1.2 (1.1, 1.6)		1.4 (1.2, 2.2)		**0.043**	1.3 (1.1, 1.8)	
$KCal.d^{-1}$	380 (302, 492)	16%	357 (289, 517)	17%	0.533	362 (295, 502)	16%
Fat							
$g.day^{-1}$	70 (52, 103)		75 (48, 92)		0.634	71 (51, 99)	
$g.kg^{-1}.day^{-1}$	1.0 (0.7, 1.5)		1.2 (0.8, 1.6)		0.120	1.1 (0.7, 1.5)	
$KCal.d^{-1}$	630 (463, 931)	28%	676 (430, 826)	30%	0.634	642 (456, 887)	29%
Alcohol		3%		3%			3%

Energy Expenditure	Males (n = 84)		Females (n = 48)			Overall (n = 132)	
Daily Energy Expenditure ($KCal.d^{-1}$)	2524 (2260, 2866)	100%	2120 (1921, 2348)	100%	**<.001**	2362 (2134, 2735)	100%
Average BMR ($KCal.d^{-1}$)	1665 ± 177	64%	1353 ± 99	63%	**<.001**	1519 (1387, 1722)	64%
Running-related EE ($KCal.d^{-1}$)	556 (405, 680)	21%	457 (362, 591)	23%	**0.039**	528 ± 218	22%
Non-running-related EE ($KCal.d^{-1}$)	113 (0, 265)	8%	118 (6, 256)	9%	0.633	113 (0, 260)	8%
TEF ($KCal.d^{-1}$)	167 ± 18	6%	135 ± 10	6%	**<.001**	152 (139, 172)	6%
Energy Balance	Males (n = 80)		Females (n = 46)			Overall (n = 126)	
Daily Energy Balance ($KCal.d^{-1}$)	-13 ± 1017		114 ± 895		0.483	33 ± 973	

Data reported are from the 2014 sample group only. Data are presented as mean ± SD or median (IQR). CHO: carbohydrates; BMR: basal metabolic rate; EE: energy expenditure; TEF: thermic effect of food. Bold p-values are those of statistical significance.

Table 12. Comparison of Energy Intake and Energy Expenditure for the Males, Females, and Overall Sample between the 2014 and 2024 Groups.

	Males (n = 114)			Females (n = 75)			Overall (n = 189)		
	2014 (n = 80)	2024 (n = 34)	p-value	2014 (n = 46)	2024 (n = 29)	p-value	2014 (n = 126)	2024 (n = 63)	p-value
Energy Intake									
Daily Energy Intake ($KCal.d^{-1}$)	2462 (1874, 3089)	2250 (1811, 3379)	0.244	2275 ± 890	2500 ± 1015	0.316	2373 (1779, 2992)	2282 (1849, 3335)	0.861
CHO									
$g.day^{-1}$	305 (241, 397)	261 (194, 413)	**0.012**	283 ± 129	285 ± 134	0.958	302 (230, 377)	264 (199, 389)	0.115
$g.kg^{-1}.day^{-1}$	4 (3.3, 5.3)	3.2 (2.3, 4.9)	**0.002**	4.7 (2.6, 6.1)	4.6 (3.4, 5.9)	0.845	4.2 (3.2, 5.8)	3.9 (2.7, 5.4)	0.219
$KCal.d^{-1}$	1219 (964, 1587)	1044 (778, 1656)	**0.012**	1133 ± 514	1139 ± 535	0.958	1209. (920, 1508)	1055 (794, 1555)	0.115
Protein									
$g.day^{-1}$	95 (75, 123)	102 (80, 141)	0.864	96 ± 43	101 ± 38	0.594	91 (74, 126)	101 (77, 137)	0.496
$g.kg^{-1}.day^{-1}$	1.2 (1.1, 1.6)	1.3 (0.9, 1.9)	0.566	1.6 ± 0.7	1.8 ± 0.8	0.290	1.3 (1.1, 1.8)	1.4 (1, 1.9)	0.343
$KCal.d^{-1}$	380 (302, 492)	407 (321, 566)	0.864	382 ± 171	403 ± 151	0.594	362 (295, 502)	406 (307, 549)	0.496
Fat									
$g.day^{-1}$	70 (52, 103)	85 (65, 122)	0.631	75 (48, 92)	87 (70, 120)	0.025	71 (51, 99)	87 (66, 120)	**0.017**

$g.kg^{-1}.day^{-1}$	1.0 (0.7, 1.5)	1.1 (0.7, 1.7)	0.882	1.2 (0.8, 1.6)	1.6 (1.2, 1.9)	0.014	1.1 (0.7, 1.5)	1.3 (0.9, 1.8)	**0.005**
KCal.d-1	630 (463, 931)	762 (582, 1098)	0.631	676 (430, 826)	785 (626, 1077)	0.025	642 (456, 887)	785 (598, 1079)	**0.017**
	Males (n = 119)			Females (n = 78)			Overall (n = 197)		
	2014 (n = 84)	2024 (n = 35)	p-value	2014 (n = 48)	2024 (n = 30)	p-value	2014 (n = 132)	2024 (n = 65)	p-value
Energy Expenditure									
Daily Energy Expenditure ($KCal.d^{-1}$)	2524 (2260, 2866)	2742 (2619, 3166)	**0.031**	2120 (1921, 2348)	2037 (1830, 2145)	0.109	2362 (2134, 2735)	2493 (2042, 2816)	0.961
Average BMR ($KCal.d^{-1}$)	1686 ± 18	1775 ± 29	**0.015**	1353 ± 99	1327 ± 107	0.270	1519 (1387, 1722)	1581 (1327, 1822)	0.950
Running-related EE ($KCal.d^{-1}$)	539 ± 24	599 ± 39	0.211	457 (362, 591)	414 (325, 502)	0.152	522 ± 18	514 ± 26	0.803
Non-running-related EE ($KCal.d^{-1}$)	113 (0, 265)	221 (110, 411)	0.423	118 (6, 256)	130 (82, 208)	0.658	113 (0, 260)	1767 (92, 2912)	0.824
TEF ($KCal.d^{-1}$)	169 ± 2	177 ± 3	**0.015**	135 ± 10	133 ± 11	0.270	152 (139, 172)	158 (133, 182)	0.950
	Males (n = 114)			Females (n = 75)			Overall (n = 189)		

	2014 (n = 80)	2024 (n = 34)	p-value	2014 (n = 46)	2024 (n = 29)	p-value	2014 (n = 126)	2024 (n = 63)	p-value
Energy Balance									
Daily Energy Balance ($KCal.d^{-1}$)	33 ± 115	-436 ± 183	**0.039**	114 ± 895	456 ± 1046	0.135	31 ± 92	39 ± 132	0.962

Data are presented as mean ± SD, adjusted mean ± SE, or median (IQR). CHO: carbohydrates; BMR: basal metabolic rate; EE: energy expenditure; TEF: thermic effect of food. Bold p-values are those of statistical significance.

5.3.4 Comparison of Macronutrient Contribution to Total Energy Intake Distribution Between the Years

Figure 15 depicts the percentage difference of macronutrient distribution of the participants in 2014 and 2024. The consumption of CHO decreased by 10%, protein increased by 3%, and fat increased by 6%. However, only the increase in fat contribution was statistically significant ($p = 0.01$).

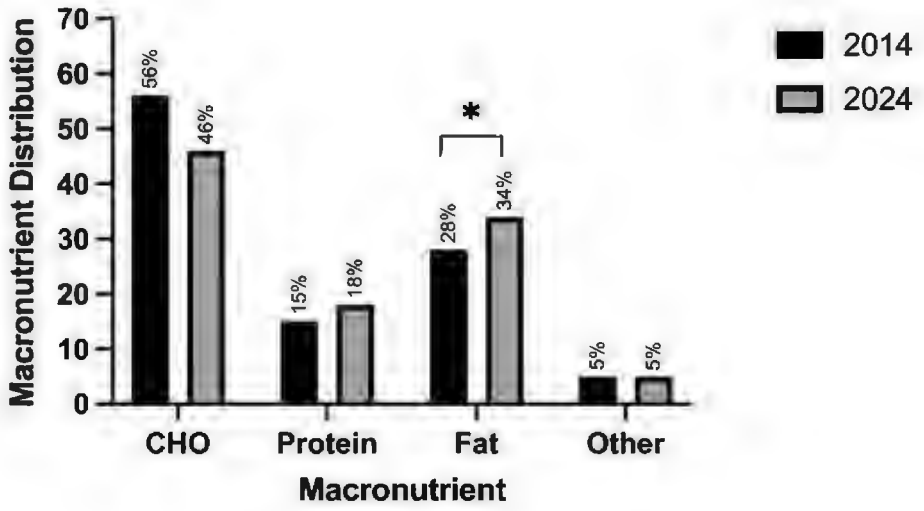


Figure 15. Percentage differences in macronutrient distribution between 2014 and 2024 participants (n = 189). *Significant between-group differences (p = 0.010)

5.3.5 Macronutrient Intake on the Days Immediately Before a Marathon

5.3.5.1 CHO-Loading

Of the 2014 participants, 63% reported CHO-loading on the days before competing in a marathon, compared to 59% of the 2024 sample. The difference between loading patterns from 2014 and 2024 is seen in Figure 16.

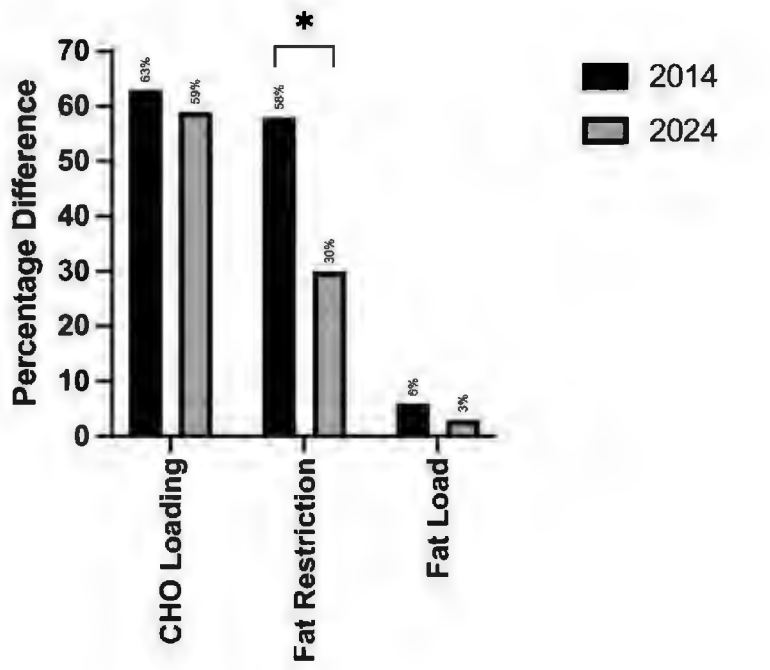
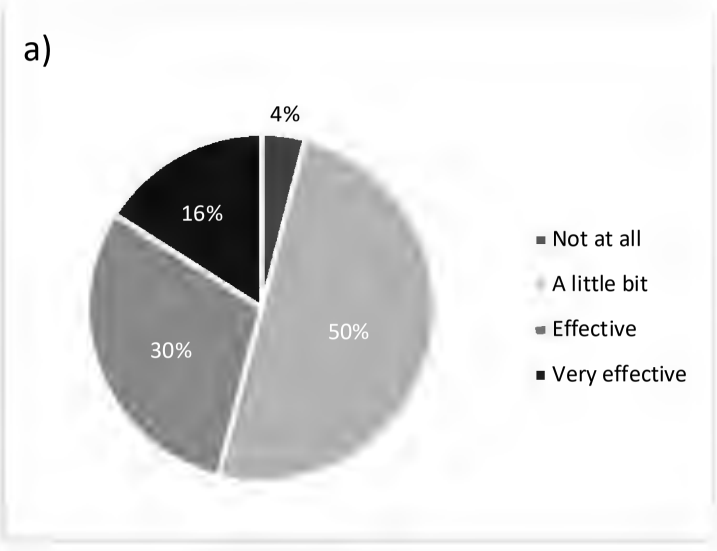


Figure 16. Percentage differences in macronutrient intake on the days immediately before a marathon between 2014 and 2024 participants (n = 222). *Significant between-group differences (p = 0.019)

Of the 63% of 2014 participants who CHO-loaded, 30% perceived it as 'effective' (Figure 17). No significant difference was seen between genders (p = 0,400). When comparing the perceived efficacy of CHO-loading between the 2014 and 2024 samples, a larger percentage of the 2024 participants perceived CHO-loading as "effective" in enhancing their performance (60%, vs 30% for 2024 vs 2014, respectively) (p = 0,015). The majority (62%) of the 2014 participants who CHO-loaded began so 2-3 days before the event, which did not differ between 2014 and 2024.



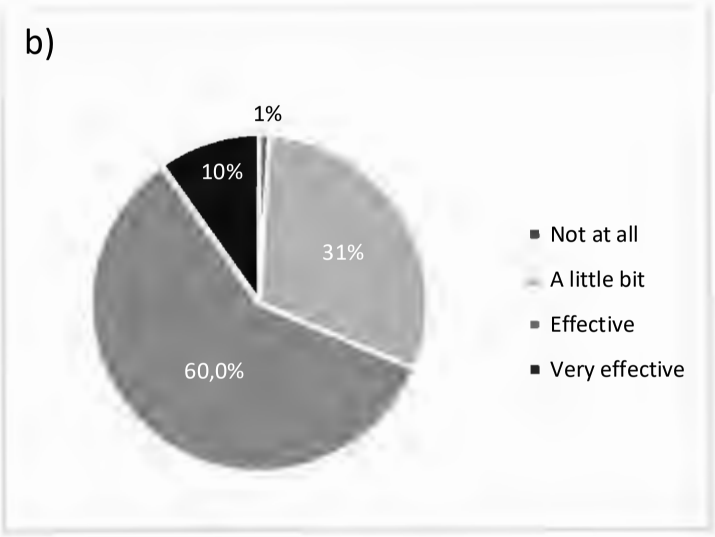


Figure 17. Percentage differences in the perceived effectiveness of CHO-loading between a) 2014 (n =159) and b) 2024 participants (n = 65). Significant between-group differences (p = 0.019).

Figure 18 depicts that the most popular foods used to CHO-load were pasta (92%), potatoes (83%), and CHO drinks (73%), which did not differ between genders or years.

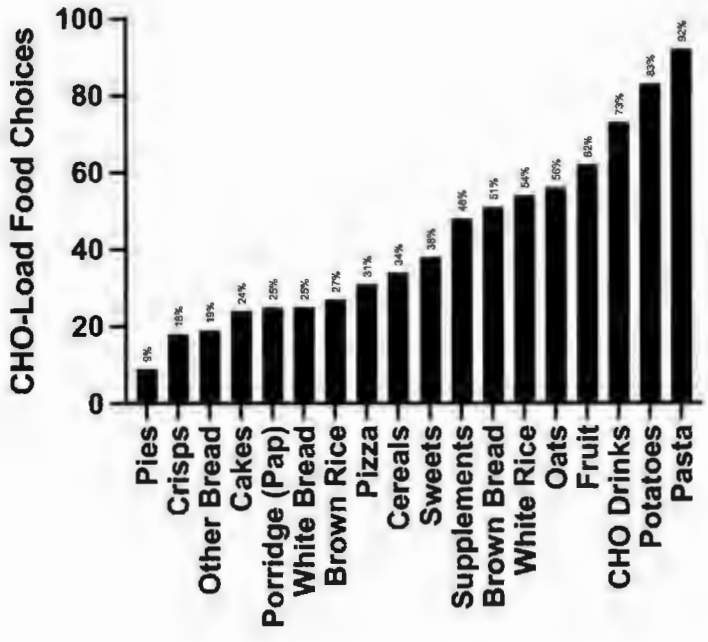
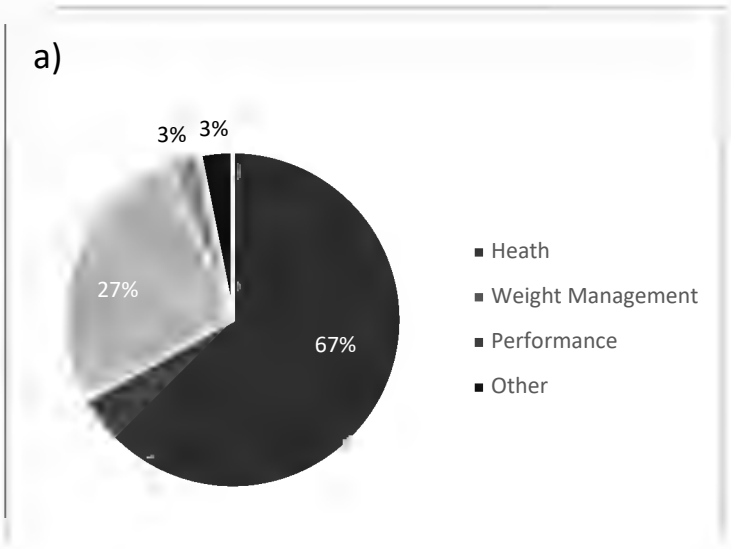


Figure 18. Food Choices used for CHO-Loading (2014 population n = 159).

5.3.5.2 FAT-Loading or Restriction

Of the 2014 participants, only 6% reported fat-loading or increasing their fat intake before competing in a marathon, which did not differ between genders or years. Less than half of the participants opted to restrict their fat intake (46%) in 2014, and men were more prone to restrict fat intake when compared to women (64% vs 47%, respectively) ($p = 0.038$). Of those who chose to restrict their fat intake, 66% claimed they restricted their fat intake for health reasons, as seen in Figure 19a. The males ($p < 0{,}001$) and the overall sample ($p < 0{,}001$) revealed significant differences between 2014 and 2024, as fewer participants restricted fat intake in 2024 (Figure 19b). Additionally, when comparing the samples between years, the reasons for fat restriction differed significantly ($p = 0{,}019$), as the 2024 participants restricted fat intake equally due to health reasons (37%) and weight management (37%).



b)

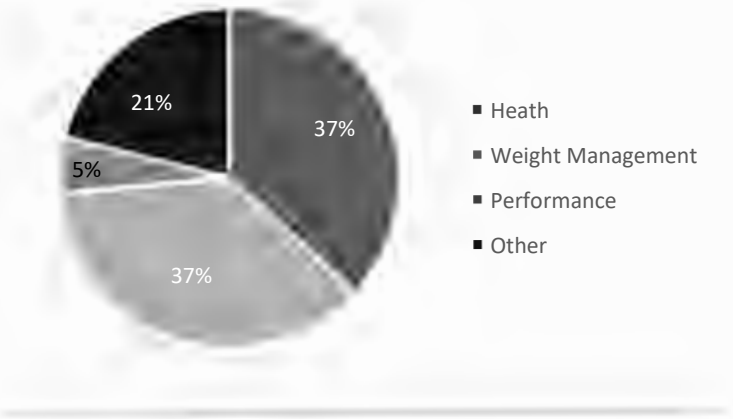


Figure 19. Percentage differences in the reasons for restricting fat intake between a) 2014 (n =159) and b) 2024 participants (n = 65). Significant between-group differences (p = 0.019).

5.4 Discussion

The key findings of this study include the description of the macronutrient distribution ranges of South African marathon runners, of which daily CHO falls below the recommended daily intake for endurance athletes (< 5 $g.kg^{-1}.day^{-1}$) [184,32]. Additionally, more than half the population of participants from 2014-2024 chose to CHO-load on the days before a marathon, of which 30% (2014 cohort) and 60% (2024%) self-reported perceiving it as an effective strategy in improving their performance. Finally, the study found that participants in 2024 were less likely to restrict their fat intake than in 2014. However, less than 6% of runners chose to fat-load on the days before a race from both cohorts.

The participants of this study showed the macronutrient distribution of South African marathon runners varied between 46-52 % CHO, 16-17 % protein, and 29-34 % fats, from 2014-2024, meeting the recommended guidelines of The Food and Nutrition Board of the Institutes of Medicine (IOM) [31,230]. However, these recommendations apply to the general public, whereas the study participants, as marathon runners, represent a highly active subgroup. Burke, et al [32] recommend a diet of 60% CHO, 15% protein, and 25% fat for endurance athletes, encouraging athletes to consume 8-12 $g.kg^{-1}.d^{-1}$ CHO [31,32,212]. However, the runners in this study consumed insufficient amounts of CHO (< 5 $g.kg^{-1}.d^{-1}$) based on these and similar recommendations [34].

Consideration should be given to the habitual diet of the highly successful runners from Kenya, particularly the Kalenjin population who reside within the Great Rift Valley. This group of

runners has a disproportionately large number of Olympians, who, between 1987-1997, won 40% of all major international middle- and long-distance running competitions [231]. A 2004 [231] study determined that the habitual diets of this group comprised 77% CHO (10 $g.kg^{-1}.day^{-1}$). To this end, the Kalenjin's high habitual CHO diet has been associated with their performance and is a likely reason for many podium wins [231]. However, their success is also influenced by a combination of factors, including lifetime exposure to high altitude, early initiation into structured training, genetic predisposition, and strong financial incentives, all of which contribute to their dominance in distance running [231]. When discussing the diet of Kenyan elites, it is important to note that total energy intake has sometimes been reported as modest relative to training demands [231], raising the possibility that such dietary practices may not always achieve optimal energy balance despite supporting glycogen availability. This nuance is important, as it highlights that even among the most successful endurance populations, dietary practices are not without potential drawbacks. In the context of the present study, this reinforces the need to consider not only macronutrient composition but also total energy availability when evaluating the adequacy of South African runners' diets.

When investigating the result of inadequate CHO consumption, evidence supports a reduced ability to synthesize adequate muscle glycogen stores, providing less energy for endurance performance [12]. A study conducted on the metabolic factors limiting performance in marathon runners identified low glycogen stores as a predominant limiting factor in exercise performance [232]. Runners with low glycogen stores are likely to reduce their pace substantially, hence the importance of synthesizing large stores. The average energy cost of running is 1 $KCal.kg^{-1}.km^{-1}$, therefore a 70 kg male would require ± 2900 KCal to run a marathon [232]. Although the body can metabolize CHO, fats, and protein to sustain this energy demand, during high-intensity exercise above 70% VO_2max, the body favours CHO in the form of glycogen and blood glucose due to its fast metabolism and uptake into the muscle cell [5,58] – as discussed in section 2.2. This raises concerns about the inadequate CHO consumption of the participants in this study.

Eating a diet inadequate in CHO affects not only glycogen stores preceding a race but also the ability to resynthesize stores after a race [14]. Research by Costill, et al [14] compared the effects of muscle glycogen resynthesis rates in trained athletes. The participants completed a bout of running until exhaustion, after which they consumed either a HC (75% total daily intake from CHO) or a low-CHO intake for 48 hours. By testing muscle biopsy samples, the study showed the participants in the HC diet group exhibited an increased rate of muscle glycogen resynthesis and higher levels of glycogen synthase activity [14]. Participants following the HC diet were also

able to replenish their muscle glycogen stores to 60-90% of their pre-exercise stores within the first 24 hours, whereas the low-CHO group's muscle glycogen stores remained depleted for the first 24 hours post-exercise [14].

Recent commentary has reinforced the notion that marathon runners of different calibers, while competing in the same event, experience differences in physiology, race intensity, and nutritional demands [63]. For recreational runners, whose relative exercise intensity is typically lower than that of elite athletes, habitual macronutrient intake may appear sufficient, particularly if carbohydrate loading is undertaken prior to competition. However, the prolonged duration of exercise still places a heavy reliance on carbohydrate availability, and the daily demands of marathon training cycles necessitate consistent glycogen resynthesis between sessions [63]. Accordingly, while carbohydrate loading (10–12 $g.kg^{-1}.d^{-1}$) is the most effective pre-race strategy, a habitually high-carbohydrate diet remains advantageous to sustain training quality and recovery in both elite and non-elite athletes.

The recommended dietary allowance (RDA) for protein intake is 0.8 $g.kg^{-1}.d^{-1}$ for the general population; however, 1.2-2.1 $g.kg^{-1}.d^{-1}$ is recommended for endurance athletes [31,215]. Active individuals require more protein than sedentary counterparts to support greater lean muscle mass, increased protein oxidation, and nitrogen balance for recovery [212]. The participants in this study consumed 1.4 ± 0.6 $g.kg^{-1}.d^{-1}$ of protein, falling within recommendations for endurance athletes [31].

Although no specific RDA exists for fats, they are recommended to constitute the remaining calories needed for weight maintenance after CHO and protein needs are met. The IOM suggests an AMDR for fats of 20-35% of total daily energy intake [31]. The participants in the study consumed 29-34%, falling within the recommendations [31]. Individuals are encouraged to limit fat intake to 30% daily due to the high energy contribution [33], however, no less than 20% should be achieved, as it may result in decreased high-density lipoprotein (HDL) cholesterol levels [230] which is associated with increased cardiovascular disease risk [233]. Tiller, et al [215] suggest 1.0-1.5 $g.kg^{-1}.d^{-1}$ of fat is required for endurance training, which was met by the runners of this study, who consumed 1.1 ± 0.5 $g.kg^{-1}.day^{-1}$. Similarly, Burke et al [32] recommend a fat intake of 25% of TE for endurance athletes [32]

The macronutrient distributions seen in this chapter are similar to the results from Chapter 5 (46% CHO, 21% protein, and 30% fat). Additionally, these results are comparable to other evidence in endurance runners, such as Kulecka, et al [227] who summarised the dietary habits of

14 elite Polish marathon runners. These athletes achieved a energy intake of 2 650 KCal.d^{-1}, distributed as 45% CHO, 21% protein, and 34% fat [227] . Indicating a macronutrient distribution lower in CHO compared to South African runners. Additionally, Wilson [228] observed 422 Eau Claire Marathon finishers from the United States, who completed a survey describing their dietary habits. Of these participants, 6.6% adhered to a LCHF diet (10% CHO, 30% protein, 60% fat), and 27% followed a high-CHO, low-fat diet (HCLF) (60% CHO, 20% protein, and 20% fats), resembling recommendations from Burke, et al [32]. However, most participants (66%) followed a moderate-CHO (40%), moderate-fat (40%), and low-protein (20%) diet [228]. Thus, many runners consume inadequate CHO.

Similarly, Peters, et al [226], analysed 173 South African 90-km ultramarathon runners' dietary intakes in 1997. The athletes had a daily macronutrient distribution of 50% CHO, 17% protein, and 32% fat [226]. Thus, they consumed 3% higher CHO, 1% higher protein, and 3% lower fat compared to the participants in this study. This indicates very little difference in eating habits over the last 20 years between marathon and ultra-marathon runners [226].

Maintaining daily energy balance is crucial to sustaining optimal performance [3]. An unequal energy balance would negatively affect endurance performance and potentially long-term health. Relative energy deficiency in sport, known as RED-S occurs in athletes due to underconsumption, and/or excessive overtraining [234]. The habitual intake of the participants of this study was well balanced, as daily energy intake (2373 KCal.day^{-1}) and expenditure (2361 KCal.day^{-1}) resulted in a minor daily surplus of 33 ± 972 KCal.day^{-1}. The daily energy consumption was slightly less than the evidence observed by Kulecka, et al [227] (2650 KCal.day$^{-1)}$ in a group of champion elite marathon runners. The reason for this is that the population of this study was not elite, but rather competitive marathon runners, hence a lower training load and energy requirement are needed. A very similar calorie intake, expenditure, and overall balance was seen in the results from Chapter 5 (calorie intake = 2491 KCal, expenditure = 2461 KCal, overall energy balance = + 30 KCal).

When comparing the dietary habits of South African marathon runners from 2014 to 2024, no significant differences were observed in overall daily energy intake, expenditure, or energy balance. However, macronutrient consumption shifted, with males reporting decreased CHO intake and females, along with the overall sample, showing increased fat intake. This suggests that while overall energy intake, expenditure, and energy balance remained consistent, specific macronutrient distributions changed over the decade within marathon runners.

When questioned about their dietary habits on the days leading up to a marathon, 59% reported CHO-loading in 2014 and 63% in 2024. The most common time frame to begin CHO-loading was 2-3 days before a marathon, which follows optimal race preparation guidelines [53]. As discussed in section 2.2.1.3, CHO-loading is effective within 1-3 days, with elite athletes typically requiring no more than one day to optimize glycogen stores. Despite more than half of the participants CHO-loading, only 30% perceived it as effective in improving their race performance in 2014. However, this significantly increased in the 2024 sample to 60% ($p = 0,015$). When considering the low daily intake of CHO in the participants' habitual diets, it is possible they were under-consuming during CHO-loading as well. Unfortunately, this study did not collect data on the participants' macronutrient intake whilst CHO-loading. Future research should investigate the intake of runners during this period to understand if recommendations are being adhered to. To this end, meeting CHO recommendations is difficult, considering a 70 kg highly active runner would need to consume 700 g of CHO daily to meet CHO-loading recommendations. One large potato contains ± 40g CHO; therefore, if this runner were to eat only potatoes, 20 potatoes per day would be required to meet these recommendations. Although runners and athletes have a variety of food and drink choices to choose from, inadequate CHO intake is still prevalent [53].

The three most popular foods used to CHO-load by the participants were pasta (used by 92% of the participants), potatoes (83%), and CHO drinks (73%), with no significant differences seen over the 10 years. The glycaemic index of pasta, the most popular choice, is considered low (< 55) on the Glycaemic Index (GI), which is discussed in Chapter 2, section 2.2.1.2. When CHO-loading, preference should be given to high GI foods as they elicit a higher blood glucose response, resulting in more rapid synthesis of glycogen stores. A recent study on different GI foods and their effect on muscle glycogen synthesis and exercise performance was conducted on a group of 87 runners [16]. The participants were divided into three groups, two following a HC diet (50-60% total daily intake from CHO) and one following a low-CHO-high-fat (LCHF) diet (> 65% of daily intake from fats). Of the two HC groups, one group consumed foods with a low GI (< 50), while the other consumed foods with a high GI (> 70) throughout the 10-week study [16]. When measuring the effects of each diet, results showed the high GI group experienced faster running speeds during a 5km time-trial from week 0 until week 10, as well as an increase in muscle glycogen content when compared to the low GI and LCHF groups, which saw no change in muscle glycogen stores[16]. To this end, if the participants were to opt for high-GI

foods, such as sweets, Chelsea buns, and high-sugar sodas, the formation of glycogen would likely be increased, potentially improving perceived efficacy [16.]

There was a significant increase in habitual fat intake over the past decade (mean absolute daily fat intake of 71 g.day^{-1} vs 87 g.day^{-1}; 2014 vs 2014, respectively), which is likely due to the popularity of the Banting and Keto diet within the 2000s, as presented in Chapter 2, section 2.2.2.1. However, when investigating the effects of HF diets in endurance settings, results often show reduced exercise capacity, primarily due to inadequate CHO stores to provide energy at higher intensities [97,235]. This can manifest as slower time-trial (TT) times, impaired ability to sustain high-intensity efforts, and diminished training adaptation, all of which may ultimately hinder overall race performance [236]. Such reductions in exercise capacity are often associated with the decreased intake of CHO, therefore reducing the reliance on CHO metabolism during exercise, which physiologically reduces the ability to perform at high intensities [58]. Despite the habitual increase in fat intake, very few runners reported intentionally choosing to fat loading on the days before an event (< 6% of both the 2014 and 2024 participants). This is not surprising, following the lack of interest in the HF diet when recruiting participants for the experimental trial presented in Chapter 5. Based on the information presented in Chapters 4 and 5, it can therefore be deduced that a HF diet (> 70% daily intake from fat) is not preferable among South African marathon runners.

When questioned if they chose to fat restrict on the days before a marathon, 58% of the 2014 participants reported doing so, which decreased significantly to only 30% in the 2024 sample. This indicates that although following a HF diet in the month before, or fat loading on the days before a marathon is not popular, marathon runners are less likely to restrict their fat intake in 2024 compared to a decade ago.

The reasons for fat restriction also differed significantly between the two groups. In 2014, 60% cited health reasons for fat restriction, and 28% cited weight management, while in 2024, participants were equally motivated by health reasons (37%) and weight management (37%). For many years, fat has been villainized as characteristically “fattening” due to its larger KCal yield per gram when compared to CHO and protein (9 KCal.g^{-1} vs 4 KCal.g^{-1}, respectively) [109]. Hence, the participants in this study most likely believe that fat intake results in fat storage, as 28-37% of the 2014 and 2024 samples were motivated by “weight management” as the primary reason for fat restriction. However, this is not the case, as evidence suggests that weight management and fat mass are primarily determined by an excess of energy intake, irrespective

of the macronutrient distribution (in healthy participants free of chronic lifestyle disease) [109]. This highlights the need for nutrition education.

It should be noted that these dietary patterns may be shaped by local context. In South Africa, the public promotion of HF, low CHO approaches to endurance performance has been particularly prominent over the past decade [237,238], which may have influenced athlete choices and perceptions. Consequently, while the present findings provide valuable insight into South African marathon runners, caution is required in extending these results to runners in other regions.

5.5 Conclusion

The findings of this study suggest that a balanced macronutrient diet best describes the habitual dietary intake of South African marathon runners, with a macronutrient distribution of 46-52 % CHO, 16-17 % protein, and 29-34 % fats, from 2014 to 2024. This study raises concerns about the inadequate CHO intake for endurance runners (< 6 0% total intake), although protein and fat intake meet requirements. Increased awareness of the benefits of adequate habitual CHO intake, alongside practical strategies to achieve it, could enhance runners' ability to sustain high-intensity exercise and potentially improve race outcomes. In addition, the dietary strategies followed on the days before competing in a race include CHO-loading and fat restriction; however, very few runners choose to fat load (< 6%). Surprisingly, only 30% (2014) and 60% (2024) of the participants who CHO-loaded found it effective in improving their performance. This highlights additional concerns about CHO intake, which may not be adequate during the CHO-loading phase. This study contributes to the growing body of research on endurance nutrition, particularly in the South African context, and highlights areas for future research and dietary education initiatives among endurance runners.

5.6 Strengths and Limitations

Several limitations within this study should be recognised and considered. The sample sizes collected in 2014 and 2024 cannot be used to represent the entire South African marathon runner population. Furthermore, although 159 participants were originally recruited in 2014, data from 27 were excluded due to incomplete FFQs, leaving 132 valid cases. While this number remains more than adequate for detecting a medium effect size at the chosen power and significance level, the exclusions reduce the overall sample size and therefore narrow the precision of estimates. In addition, the smaller comparator group reduces confidence in detecting very small differences between cohorts. Future work would benefit from larger

samples to increase statistical power for detecting subtle changes in dietary intake. Additionally, variables were self-reported and based on recall, making them susceptible to measurement errors, recall bias, and portion size inaccuracies [239], which may not accurately represent the true situation [240]. Despite well-developed questionnaires being utilised, no objective method was used to verify the dietary habits of these participants. Furthermore, the FFQ may not have contained all food items consumed by participants, further limiting the accuracy of recorded dietary intake. Estimates of running frequency and distance, and non-running-related sports participation, could have been susceptible to recall bias, therefore affecting participants' estimated energy expenditure. Finally, TEF measurements vary for different foods and nutrient compositions, and therefore, standardizing the TEF to 10% of RMR for each participant is a generalized estimation [241].

The CHO and fat-loading strategies were assessed using binary yes/no responses (a dichotomous variable), which limited the depth of data collected and did not capture specific details through dietary recall or tracking. This approach prevents a thorough understanding of the extent and accuracy of loading practices. Future studies should implement more precise methods, such as requiring participants to record their energy and macronutrient intake on the days leading up to the race, to accurately determine whether effective loading is occurring and if recommended targets are being achieved.

5.7 Acknowledgements

This chapter was developed as part of an Honors Research Project, which I co-supervised. I identified the need to investigate the dietary habits of marathon runners for this thesis. The FFQ development and 2014 data collection were conducted by Professor Marjanne Senekal and Associate Professor Janetta Harbron. I supervised the recruitment of participants and collected the 2024 data. I was the primary author of the manuscripts on which this chapter is based.

Chapter Six: Overall Summary

6.1 Introduction

The study of dietary habits before and during exercise is a multifaceted area of nutrition, which encompasses a thorough understanding of the timing, dosage, and distribution of all three macronutrients. CHO is a well-established fuel source for endurance performance, effectively extending exercise capacity and delaying fatigue. However, as exercise duration increases, CHO depletion becomes inevitable, eventually leading to fatigue. To mitigate this, sports nutritionists and physiologists have explored alternative fuel sources to sustain performance during prolonged exercise. Due to the body's large fat storage potential, the use of fats is attractive in long-duration exercise performance, but finding conclusive evidence is difficult. The evidence varies greatly, and a definitive answer to whether fats can be used as effectively as CHO is unavailable. However, evidence is available on the efficacy of combining CHO and fats, either in the form of diet, such as following a HF diet for several weeks and CHO-loading the days before exercise testing, or supplementation combining CHO and fats.

Hence, this study aimed to compare the use of different dietary habits, both habitually and through supplement form, on exercise performance. However, due to the lack of runners willing to change their habitual diet, only supplementation could be tested. Furthermore, the study aimed to define the current dietary habits followed in the month before, and CHO or fat-loading strategies used on the days before a marathon-by-marathon runners.

6.2 Key Findings

Chapter 2: The Literature Review highlighted the importance of CHO stores in long-duration events such as marathon running. It showed the importance of substantial CHO stores in the form of liver and muscle glycogen before a race, and supplementing with CHO during a race to optimise performance. Despite adequate CHO sources, eventual fatigue is unavoidable, and an alternate fuel source is needed. Further, the chapter introduced research investigating the potential use of fat as fuel to spare glycogen, through diet and supplementation. Research evidence showed that HF diets commonly resulted in reduced exercise capacity at high intensities, likely because of low glycogen stores at the beginning of exercise. To this end, subsequent research showed the efficacy of using a HF diet for weeks before testing and then allowing for 2 – 3 days of CHO-loading, which elicits the benefits of increased fat oxidation during exercise, and adequate glycogen stores to fuel high-intensity exercise. This dietary combination proved successful in maintaining exercise performance.

The use of MCT supplementation was introduced, providing a review of the metabolism and use of MCT in endurance exercise. The timing and dosage of MCT were discussed, as was the prevalence of gut discomfort. The lack of evidence in runners was highlighted, with only two studies available for review. This chapter introduced the use of MCT but did not provide an exhaustive review of the available literature, as this is the focus of the subsequent chapter.

Chapter 3: The Scoping Review aimed to map the current literature and understanding of the effects of MCT on exercise performance. This chapter noted the large variation in the timing and dosage of supplements, making it difficult to define the best practice of either. The performance effects of MCT were commonly negative, resulting in no performance improvements within any of the studies. The general effects of MCT supplementation include elevated resting plasma BHB concentrations and increased fat oxidation. Additionally, gut discomfort was commonly experienced with both high (60-85 $g.hr^{-1}$) and low doses (< 30 $g.hr^{-1}$), although discomfort was minimal in lower doses. The strategy of gut training was discussed, as evidence shows the potential in reducing gut discomfort with regular use of MCT. This chapter highlighted the possibility of combining MCT and CHO, as two studies observed improved time trial performance in the MCT+CHO groups compared to MCT or CHO alone.

Notably, this scoping review identified the lack of evidence in runners, identifying only two research studies. Additionally, the study found no evidence of MCT within female endurance athletes or in recent literature after 2005.

Chapter 4: The experimental trial originally aimed to compare the effects of different diets (HF vs HC diets) and supplement conditions (CHO, MCT, or MCT+CHO). However, recruiting 10 runners following a HF diet proved impossible, and no runners made themselves available for testing. Additionally, none of the 20 recruited runners following a HC diet were willing to change to a HF diet. As a result, the comparative diet component of the study was excluded. Therefore, this chapter presented and discussed results observed when combining MCT, CHO, or MCT+CHO supplements during running performance.

The findings of this study show no difference in TT performance between the three conditions. The MCT+CHO condition did, however, result in decreased HR and RPE compared to the MCT and the CHO condition. Furthermore, the use of MCT, when used alone or in combination with CHO, enabled the maintenance of euglycemic plasma glucose concentrations during 90 minutes of running. Although CHO oxidation was similar between the CHO and MCT+CHO conditions, MCT alone had a CHO-sparing effect, reducing the use of CHO in this condition.

Additionally, increased fat metabolism during steady-state exercise was noted in the MCT condition; however, this did not improve performance when ingested alone.

Although not initially outlined in its aims, the study identified a low CHO distribution (< 50%) in the participants' habitual diets. This instigated further research, determining the dietary habits of marathon runners in the month before a marathon and the CHO or fat-loading strategies followed on the days immediately before a marathon.

Chapter 5: This Observational Study aimed to further understand the dietary habits of South African marathon runners. Two cohorts were compared from 2014 and 2024, showing that runners' diets were well-balanced, with a small energy surplus of 30 $Kcal.day^{-1}$. Their macronutrient distribution ranges from the 2014 and 2024 cohorts varied between 46-52 % CHO, 16-17 % protein, and 29-34 % fats, meeting the recommended guidelines of the IOM. However, these recommendations apply to the general public, whereas the study participants, as marathon runners, represent a highly active subgroup. The recommended diet for endurance runners is > 60% CHO, encouraging athletes to consume 8-12 $g.kg^{-1}.d^{-1}$ CHO. However, the runners in this study consumed insufficient CHO of 4.7 ± 2.1 $g.kg^{-1}.d^{-1}$, not meeting recommendations. The lower CHO intake raises concerns about inadequate fuelling during marathons. Additionally, the study revealed a significant increase in fat intake over the past 10 years, with the habitual diets of runners being 5% higher in fat compared to 2014.

Furthermore, the study aimed to describe the CHO and fat-loading strategies followed by marathon runners on the days before a race. The results showed 58-63% of marathon runners opt to CHO-load on the days before a race, with 30-60% perceiving it as effective in improving their performance (ranges are from 2014 to 2024). The lack of perceived effectiveness was associated with incorrect food choices during CHO-loading, which were low GI. Given the runners' moderate habitual CHO intake, which falls below recommended levels, it is likely that they also did not meet CHO-loading recommendations.

Notably, less than 6% of marathon runners opt to fat-load on the days before a race. This evidence, combined with the findings showing habitual fat intake of 29–34%, supports the absence of HF runners recruited in Chapter 4. Finally, this chapter found that although runners are not likely to fat-load or increase their fat intake in preparation for a race, they are less likely to restrict their fat intake in 2024 than they were in 2014.

6.3 Evaluation of the Original Hypothesis

Dietary Comparison Hypothesis:
The evidence provided in the literature review supported the original hypothesis, showing endurance performance differs substantially between athletes consuming either HF or HC diets. A large body of evidence consistently observed HC diets resulted in improved endurance performance, particularly when conducted at a high intensity (above 85% VO_2max) compared to HF diets.

MCT and Performance Hypothesis:
The experimental trial supported the hypothesis, and the use of MCT alone did not improve exercise performance when compared to CHO. However, the addition of MCT+CHO did not result in a change in performance when compared to CHO or MCT alone.

Dietary Habits Hypothesis:
The observational study showed that although the macronutrient intake of South African marathon runners is balanced, CHO intake falls below recommendations (< 60% of total daily intake), which did not align with the hypothesis. While the majority of runners reported CHO-loading on the days before an event, half of these runners did not perceive it as effective in improving their performance. Habitual fat intake was lower than CHO intake, and very few runners chose to fat-load on the days before an event.

6.4 Direction for Future Research

Although this research bridged gaps in the literature, further research is still required on endurance running, as the majority of the evidence provided on HF and MCT is from studies on cycling. Due to the lack of success in the experimental trial to recruit participants following a HF diet, no research to date has been conducted on the effects of a HF diet followed by CHO-loading and the combination of MCT+CHO supplementation in runners.

Research should focus on extending findings from cycling to running, addressing metabolic differences between the two. Additionally, the combinations of macronutrients should be tested in highly trained, elite runners, particularly females, where no research exists. This would allow protocols at higher intensities and durations, allowing a deeper investigation of how macronutrient synergy affects substrate utilization and exercise performance.

Although this thesis collected quantified data on the macronutrient intake in the month before a marathon, no data was collected on the macronutrient intake on the days before – only self-

reported information on strategies used (e.g., CHO or fat-loading) was collected. To this end, future research should collect food logs from runners detailing the macronutrient intake on the days before a marathon to determine if macronutrient intake meets the recommendations.

6.5 Conclusion

The findings of this thesis highlight the effects of macronutrient intake, specifically of carbohydrates and fats, in enhancing endurance performance. This research demonstrates that the combination of fats and CHO can influence endurance exercise outcomes. By examining existing literature and collecting original experimental and observational data, this thesis provides a comprehensive understanding of how endurance runners can optimize their nutrition to fuel prolonged exercise.

The implications of this research are twofold. First, the combination of carbohydrates and fats for fuelling endurance performance has practical applications for improving race outcomes, particularly in marathon running, where runners require nutritional strategies to improve long-duration performance. However, very few runners choose to increase fat intake or fat load in preparation for a marathon, and eliciting a drastic increase in habitual fat intake is unlikely. Considering supplementation strategies, whilst the use of MCT supplementation, both alone and when combined with CHO, is ineffective in enhancing performance, the combination is associated with rapid gastric emptying and reduced gut discomfort. However, due to insufficient evidence supporting performance benefits, the inclusion of MCT supplementation cannot be recommended.

Second, this work highlights the existing gap in nutritional practices, particularly the underconsumption of CHO. This thesis contributes significantly to sports nutrition by describing the dietary habits used by South African marathon runners, which has not been done before. Furthermore, it emphasizes the importance of tailored nutritional education plans for athletes to ensure that carbohydrate recommendations are habitually met across the population. Additionally, nutrition education is needed on ingesting the recommended amount and types of CHO when loading for a race. Education should focus on choosing high-GI foods to use during CHO-loading. Furthermore, the use of gut training should be implemented by runners during training sessions to reduce intolerance and improve CHO absorption.

Ultimately, the insights presented in this thesis offer valuable contributions to the field of sports nutrition, providing evidence-based recommendations for both athletes and practitioners.

Optimizing macronutrient intake has the potential to enhance endurance performance, thus advancing the effectiveness of nutrition strategies in exercise science.

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Appendix A

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

Advertisement

Appendix B

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

Participant Information Sheet

Why am I receiving this letter? The University of Cape Town is conducting a research study comparing different dietary and supplement strategies and performance in endurance runners. This study forms part of the research thesis component of PhD student Devon Byrnes. If you are interested in taking part in this study, please read further.

Why are we doing this study? Carbohydrates may be well understood in the context of sports performance, but the same does not apply for fat intake and few recommendations have been constructed. Studies conducted on well-trained to ultra-endurance cyclists following a high-fat diet paired with a high-fat supplement (comprising of medium chain triglycerides – MCT) have shown improved time-trial performance and increased resistance to fatigue. The same has not been tested on endurance runners. With the high level of competitiveness world-wide, the study of the potential benefits of a high-fat diet paired with MCT supplementation to optimise performance in endurance runners could provide useful dietary methods to enhance performance.

Who is responsible for the information contained in this letter? The persons responsible for this research study are Associate Professor Andrew Bosch and Devon Byrnes, from the University of Cape Town (contact details below).

Who can take part in this sub-study? We are looking for male and female endurance runners to take part in this study. Specifically, you can take part in the study if you: older than 18 years old, can complete 21km in under 1 hour 40 minutes (males) and 2 hours (females) within the last 12 months.

Principles concerning research: your rights. You must read and understand the principles that apply to all persons who agree to participate in the research study described below:

- Taking part in the study is always entirely voluntary.
- By taking part in this study you will receive a free VO_2max test to the value of R2000, as well as a running economy test, which are both important markers in running

performance. In addition, you will receive individual feedback regarding your performance for each supplement condition, as to whether you perform better with a carbohydrate or MCT supplement. This will indicate the best supplement strategy for your future running events.

- Your privacy and anonymity will be maintained at all times. Your name, surname, identification number and any personal identifying characteristics will remain entirely confidential.
- You are free to withdraw from the study at any time without anyone objecting and without penalty or loss of any benefits to which you are otherwise entitled. The principal investigators may also decide to withdraw you from the study.

The following information will help you to decide whether or not you wish to participate. Please discuss any questions you have about this research with the study staff.

If I choose to take part, what is expected of me? We will ask you to visit the Division of Exercise Science and Sports Medicine at UCT on four occasions (in a six-week period) as follows:

Visit 1: Baseline measurements. Please refrain from any unaccustomed exercise the day before testing. You will be asked to record your training (so that the same training can be undertaken before subsequent testing). You will complete a 3-day dietary record (two weekdays and 1 weekend day) to determine your habitual diet. Your diet will be analysed using the MyFitnessPal app.

Baseline measurements will include height, weight, BMI, and body fat percentage using the Jackson Pollock 4 skinfold site method followed by a Peak Treadmill Running Speed Test and VO_2max test. This will be conducted to determine the speed for the subsequent 90-minute steady-state tests (70% peak treadmill speed). The peak treadmill speed test will begin with a warm-up of your choice, as you would normally do before a race, TT, or track workout. Following this, you will start running at a speed of 1 km.hr slower than your normal training speed, with the velocity being increased by 0.5 km.hr every half minute until voluntary exhaustion. Peak treadmill running speed will be taken as the highest speed (km/hr) maintained for a full half minute during the test plus the number of seconds at the uncompleted speed. During the PTRS maximal oxygen uptake (VO_2max) will be measured by placing a mask over your mouth and nose. VO_2max will be measured over 15-s intervals using an online breath-by-breath gas-analyser system.

A 15-minute rest period will take place before starting a 5km time-trial familiarisation run to minimize any possible learning effect in the subsequent trials.

*Visit 2-4: Experimental Trials***.** You will be tested at the same time of day for each visit, preferably in the morning following an overnight fast. A CHO breakfast containing approximately 60-65g CHO-will be given to you, which you will consume approximately 2-3hrs before scheduled testing. The food type will be determined by your preference to avoid any undesirable GI tract discomfort. You will attend three testing days, one for each of the three supplements - either the CHO, MCT, or MCT+CHO supplement, the order of which will be randomly assigned. There will be a 14-day washout period between testing days. The experimental trials include a 90-minute steady-state treadmill running protocol set at 70% peak treadmill speed, followed by a 5km TT on a treadmill.

Your heart rate (HR) and rate of perceived exertion (RPE) will be measured at the beginning of the 90-minute steady-state run and in 15-minute intervals thereafter. HR will be measured using a Polar H9 Heart Rate Sensor, RPE will be measured using the Borg scale to rate your perceived exertion on a scale of 6 – 20. In addition, at the time of the 15-minute test intervals, a mask will be placed onto your mouth and nose for 3-4 minutes to measure RER and VO_2. Blood samples will be taken via venous blood draws at the same intervals. After the final measurements have been taken at the end of the 90-minute steady state run, you will be given a chance to void your bladder, then start the 5km TT. HR, RPE, time-trial performance and rate of fatigue (pace for each km) will be measured.

How, when and why will your blood be taken? We will be taking your blood on separate occasions to measure the effect of each supplement on plasma glucose. A needle will only be inserted once and will be taken from a vein in the arm by a qualified phlebotomist under sterile conditions.

*Will you have to change your diet***?** We are looking for 10 participants that are currently following a habitual high carbohydrate diet (where > 65-75% of energy intake is from carbohydrates) and 10 participants currently following a high-fat diet (where > 65-70% of energy intake is from fats). You do not have to change your habitual diet, however, you will need to complete three days of carbo-loading before the experimental trials begin during visit 2-4.

What will be in the supplements? The supplements will consist of 10% CHO, 4,3% MCT or 10% CHO + 4,3% MCT. The CHO supplements will be a commercially available glucose

polymer. The MCT supplement will be a commercially available MCT oil of 60% caprylic and 40% capric fatty acids. All three trials will use current optimal practice of 150 ml of either 10% glucose polymer (CHO condition) or 4.3% MCT (MCT condition) before and at 15-minute intervals during the 90-minute steady state run.

Are there any risks to me if I decide to take part? There are minimal risks in taking part in this study. The study will take place in a controlled laboratory setting with trained sports scientists. Nevertheless, possible risks include falling off the treadmill or a small chance of infection form the blood draws. As you are a trained runner and are used to "hard" training and running on the treadmill, so the risk of injury is minimal. Blood draws can feel a little uncomfortable at first, but they will be taken in a sterile environment by a trained phlebotomist meaning that the risk of infection is small. We are aware that we are in the midst of the COVID-19 pandemic. Please be assured that all staff in our building are screened every day before coming to work and that the room that you will come to will be fully cleaned and sanitized. The same is true for the scale, height meter, blood pressure cuff, and heart rate monitor. We will also ask that you have your temperature measured and respond to the COVID-19 screening questions as per our building and UCT protocol before visiting us. As part of the UCT and building protocol, the wearing of masks is currently mandatory before being permitted to enter the building. In this way, we are doing all that we can to minimise the risk of infection.

Are there any benefits to me if I decide to take part? You will not be remunerated for taking part in this study; however, you will receive your baseline measurements and running performance data, which will include peak running speed, oxygen consumption and time-trial performance which can be used to improve training. You will also find out how your performance differs with each nutritional supplement, which may allow you to improve your performance.

What will happen to the information we collect? We will use the information collected to learn about the relationships between different dietary strategies and running performance. Only the study staff assigned to this project will analyse the information (but without your name or any personal identifiers). The information collected will be stored for a period of up to 5 years and will only be used for this study.

The results of this research study may be published in a scientific book (known as a journal) to help improve our knowledge of sports nutrition. We may also use the results to help appropriate

authorities guide public health recommendations. You will not be identified by name or by any other identifying information in any publication or report about this research.

What if something goes wrong? Should any injury occur, or should any untoward event happen while participating in this study, study staff and medical personnel will provide on-site emergency medical care.

This research study is covered by an insurance policy taken out by the University of Cape Town in case you suffer a bodily injury while taking part in the study. The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the rules and regulations documented by the South African Good Clinical Practice Guidelines (3rdEdition)) published by the Department of Health and SAHPRA (2020). The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the principal investigator for a copy of these guidelines.

If you are harmed and the insurer pays for the necessary medical costs, usually you will be asked to accept that insurance payment as full settlement of the claim for medical costs. However, accepting this offer of insurance cover does not mean you give up your right to make a separate claim for other losses based on negligence, in a South African court.

Freedom to withdraw and confidentiality: Your participation in the study is entirely voluntary, and you may withdraw at any time without having to explain why you wish to do so. The principal investigator may also decide to withdraw you from the study if he decides this is best for you. It is also important for you to know that your name, and any personal identifying characteristics, will remain entirely confidential. Your information will be kept in a locked file, made available only to the researchers in the study.

If you have any questions about your participation in the study, feel free to contact the student investigator (Devon Byrnes) or the Principal Investigator (Associate Professor Andrew Bosch).

Associate Professor Andrew Bosch

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You may also contact the Chairperson of the Human Research Ethics Committee, Professor Marc Blockman if you have any concerns about your welfare or any other issues or complaints that have not been adequately addressed by the investigators.

Prof Marc Blockman

marc.blockman@uct.ac.za

021 406-6338.

Appendix C

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

Consent Form

Participant ID: _____

I, the undersigned, have been fully informed about the study entitled "**An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.** " to be conducted by researchers from the Division of Exercise Science and Sports Medicine within the Department of Human Biology, Faculty of Health Sciences at the University of Cape Town. The study will be conducted according to the rules and regulations documented by the South African Good Clinical Practice Guidelines (3rd edition) published by the Department of Health and SAHPRA (2020). I understand what is involved, including the risks and benefits of taking part. I have had the opportunity to ask all the questions that I have relating to the study.

I understand that:

- Taking part is entirely voluntary.
- I am free to withdraw from the study at any time without anyone objecting and without penalty or loss of any benefits to which I am otherwise entitled.
- I will not directly benefit from taking part in the study.
- I may receive feedback on the supplements administered and my subsequent performance on completion of the study.
- My privacy and anonymity will be maintained at all times. My name, surname, identification number and any personal identifying characteristics will remain entirely confidential.
- I understand that my consent here indicates that I am willing to participate in this research study as described above.
- I will receive a signed copy of this informed consent document.

Please tick the appropriate box:

☐ I agree to participate in this study.

☐ I do not agree to participate in this study.

_____ Date:_____

(Signature: Participant)

Appendix D

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

Study Participant Questionnaire

Full Name:_____Date:_____

Age:_____Height:_____Weight:_____Gender:_____

1. Describe your current weekly training (type of exercise, duration, km covered):
2. Are you able to complete a half marathon (21km) in under 1hr 40 minutes (male) or 2 hours (female)?
3. If so, has this been within the past year?
4. What is your average 21km running pace per km?
5. Do you have any injuries currently affecting your training?
6. Do you have any chronic or lifestyle diseases affecting your training?
7. Are you currently following a diet high in carbohydrates, with 65-75% of your daily energy coming from carbohydrates (this is an estimate)?
8. If so, have you been following this diet for at least 4 weeks?
9. Are you currently following a diet high in fats, with 60-70% of your daily energy coming from fats (this is an estimate)?
10. If so, have you been following this diet for at least 4 weeks?
11. Describe your typical day of eating from breakfast-dinnerdinner.

Appendix E

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

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3 Day Food Log

3 Day Food Journal		
Meal Information	Food information	Weight
Example:		
Breakfast	Rolled Oats	2 tbsp
	Fat free milk	1 cup
	Banana	x2 small
Meal Information	Food information	Weight
Day one		
Breakfast		
Snack		
Lunch		
Snack		
Dinner		
Snack		
Liquids		

Appendix F

An Investigation of the Effects of MCTs and Carbohydrates on Running Performance in a Randomized Cross-over Study.

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3 Day Training Log

3-Day Training Journal

Meal	Day 1: _____	Day 2: _____	Day 3: _____
Morning Session	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:
Mid-day Session	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:
Evening Session	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:	Type of exercise: Intensity: KM covered:

Appendix G

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Advertisement

Appendix H

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Informed Consent Form

Participant ID: _____I, the undersigned, have been fully informed about the study entitled "Exploring the Dietary Habits Among Marathon Runners in South Africa: An Observational Study" to be conducted by researchers from the Division of Exercise Science and Sports Medicine within the Department of Human Biology, Faculty of Health Sciences at the University of Cape Town. The study will be conducted within an appropriate regulatory, legal and ethical framework, under Human Research Ethics Committee (HREC) approval.

I understand what is involved, including the risks and benefits of taking part in the study. I have had the opportunity to ask all the questions that I have relating to the study.

I understand that:

• Taking part is entirely voluntary.

• I am free to withdraw from the study at any time without anyone objecting and without penalty or loss of any benefits to which I am otherwise entitled.

• I will not directly benefit from taking part in the study.

• I may receive feedback on my dietary intake analysis upon completion of the study.

• My privacy and anonymity will be maintained at all times. My name, surname, identification number, and any personal identifying characteristics will remain entirely confidential.

• I understand that my consent here indicates that I am willing to participate in this research study as described above.

• I will receive a signed copy of this informed consent document.

Please tick the appropriate box:

☐ I agree to participate in this study. ☐ I do not agree to participate in this study.

_____ Date:_____

(Signature: Participant)

Appendix I

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Participant Information Sheet

Why am I receiving this letter? The University of Cape Town is conducting a research study to explore the dietary habits among marathon runners in South Africa. This study forms part of the research thesis component of Honours student, Morgan Naidoo, and PhD student, Devon Byrnes. If you are interested in taking part in this study, please read further.

Why are we doing this study? Although there are some findings which characterises the dietary habits of marathon runners in certain regions of the world, no recent literature has yet characterised the average marathon runner's diet within South Africa. Therefore, the purpose of the study is to explore the Dietary Habits Among Marathon Runners in South Africa, which may be beneficial for optimising health and athletic performance through successive nutritional strategies.

Who is responsible for the information contained in this letter? The persons responsible for this research study are Associate Professor Andrew Bosch, Associate Professor Janetta Harbron, Devon Byrnes and Morgan Naidoo, from the University of Cape Town (contact details below). *Who can take part in this sub-study?* We are looking for South African Marathon runners to take part in this study. Specifically, you can take part in the study if you: • Have completed one or more 42.2km marathon(s) in the last 2 years. • Between the ages of 18-60-years Participation Information Sheet 22 • Apparently healthy • Literate in English • Currently living in South Africa • injury free with no chronic or lifestyle diseases • have no food allergies and/or intolerances

Principles concerning research: your rights: You must read and understand the principles that apply to all persons who agree to participate in the research study described below:

• Taking part in the study is always entirely voluntary.

• You will not benefit directly from taking part in the study.

• As a participant, you will receive feedback relating to your own dietary intake analysis that we measure in this study.

• Your privacy and anonymity will be maintained at all times. Your name, surname, identification number and any personal identifying characteristics will remain entirely confidential.

• You are free to withdraw from the study at any time without anyone objecting and without penalty or loss of any benefits to which you are otherwise entitled. The principal investigators may also decide to withdraw you from the study. The following information will help you to decide whether or not you wish to participate. Please discuss any questions you have about this research with the study staff.

If I choose to take part, what is expected of me? We will ask you to complete a participation questionnaire for one full month. The questionnaire consists of two components, a Quantified Food Frequency Questionnaire (QFFQ), as well as a Participant Health and Lifestyle Questionnaire. The QFFQ is a dietary assessment tool that is simple to fill in and complete, not too time-consuming, is low-cost and has a low participant burden. The QFFQ is used to record participant dietary by recording all the food types and quantity of each food type that you ingested during the month. You will therefore be required to log all food and beverages ingested during the last month of training, prior to your most recent completed marathon. Visual cues and measuring tools will be provided as guidelines to help quantify your portion sizes. 23 Additionally, you will be required to answer short questions relating to your personal details, your weight history, gynaecological history (women only), exercise and sport participation information and food intake information including total energy intake.

Will you have to change your diet? No, you will not be required to change your diet. We expect you to accurately record all the food and beverages ingested during the duration of the experiment in order to characterise your habitual dietary habits.

Are there any risks to me if I decide to take part? There are minimal to no risks in taking part in this study.

Are there any benefits to me if I decide to take part? There are no direct benefits to you, should you agree to take part in this research study. You will not be remunerated for taking part in this study; however, you will receive your dietary intake analysis data, which can be used to improve training performance through successive nutritional strategies.

What will happen to the information we collect? We will use the information collected to learn about the dietary habits adopted by marathon runners in South Africa. Only the study staff assigned to this project will analyse the information (but without your name or any personal identifiers). The results of this research study may be published in a scientific book (known as a journal) to help improve our knowledge of sports nutrition in South Africa. We may also use the results to help appropriate authorities guide public health recommendations. You will not be identified by name or by any other identifying information in any publication or report about this research.

Freedom to withdraw and confidentiality: Your participation in the study is entirely voluntary, and you may withdraw at any time without having to explain why you wish to do so. The supervisor may also decide to withdraw you from the study if he decides this is best for you. It is also important for you to know that your name, and any personal identifying characteristics, will remain entirely confidential. Your information will be kept in a locked file, made available only to the researchers in the study.

If you have any questions about your participation in the study, feel free to contact the student investigator (Morgan Naidoo) or the Supervisor (Associate Professor Andrew Bosch). *Associate Professor Andrew Bosch* andrew.bosch@uct.ac.za +27 81 742 3706

Student Investigator Morgan Naidoo NDXMOR005@myuct.ac.za +27 71 149 7741

If you have any concerns with respect to the ethics of the study, please contact the Chair of the Human Research Ethics Committee (HREC), Professor Marc Blockman at marc.blockman@uct.ac.za.

Appendix J

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Participant instructions for the dietary intake questionnaire:

For the completion of the Food Frequency Questionnaire, we would like you to carefully consider what you ate and drank during the past month, for ONE FULL month. In the Food Frequency Questionnaire table, you will find a list of foods and drinks (Column 1). We would like you to indicate: 1. How often you ate or drank the specified item during one full month (Column 2). 2. On average, how much (or portion size) you ate or drank of the specified item if you did consume it (Column 3). Guidelines are given in Column 3 to help you with portion size estimation. The standard (Std) portion size of each food item or drink is indicated in Column 3 in household measures (e.g., cups, spoons, grams) or as a unit (e.g., a hamburger). Where possible, the Std portion size is also shown in terms of visual aids, including a matchbox, a tennis ball, and a sketch of half a cup of dished-up food. Sketches of these aids are attached below.

Teaspoon	tsp	Tennis ball	
Table spoon	Tbs	1/2 cup of dished up food	
Gram	g	Match box	
Millilitres	ml		
Etc. refers to further similar items			

Once you are sure about the size of the Std portion, tick one of the following options in Column 3:

• If the portion you ate/drank of the specified item on average is ± the same as the Std portion size, tick the *1X Std* column, OR

• If the portion you ate/drank of the specified item on average is less than the Std portion size, tick the *½X Std* column, OR

• If the portion you ate/drank of the specified item on average is a little more than the Std portion size, tick the *1½X Std;* OR

• If the portion you ate/drank of the specified item on average is much more than the Std portion size, tick the *2X or 3X Std* column.

Please make sure that you tick every line (all 124 different food items). If you did not eat/drink a particular item in the last month, make sure that you tick the "NO" column. Remember that if you ticked the "NO" option in Column 2, you do not have to complete Column 3 (portion size).

Appendix K

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Food Frequency Questionnaire

EXAMPLE (see first highlighted portion of questionnaire): During Jimmy's training period, one of the foods he eats is brown bread. He eats brown bread every day for breakfast and for lunch. At each meal he eats about 2 slices of bread.

Usual intake during the LAST MONTH OF YOUR TRAINING SEASON before your latest marathon														
Column 1		Column 2							Column 3					
		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
	EXAMPLE	This person eats 2 slices of brown bread twice a day.												
	BREAD/ROLLS: brown						√		1 roll or 1 med slice				√	
1	RED MEAT: low fat cuts (no visible fat) e.g. Steak, lean minces, roast, ham (beef, veal mutton, pork, venison, ostrich)								90g/ 3X ▱					
2	RED MEAT: high fat cuts e.g. Regular mince, ribs chops with fat (beef, pork, mutton)								90g/ 3X ▱					
3	HAMBURGER								1					
4	SAUSAGE: viennas, russians, frankfurt, boerewors etc.								10cm sausage					
5	MEAT STEW: e.g. chuck, neck (with or without vegetables)								1 cup or 2X ◎					
6	CHICKEN/TURKEY: with skin								90g/ 3X ▱					
7	CHICKEN/TURKEY: without skin								90g/ 3X ▱					
8	FRIED CHICKEN/ SCHNITZEL: Kentucky or homemade								90g/ 3X ▱					
9	FISH: fried in fat/oil								90g/ 3X ▱					
10	FISH: steamed, grilled, braaied (fire)								90g/ 3X ▱					
11	FISH: tinned sardines, pilchards, salmon, tuna								90g/ 3X ▱ or ½ small tin					
12	ORGAN MEATS: liver, kidney, heart, tripe (beef, sheep, chicken)								90g/ 3X ▱					
13	SMOKED/CURED: meat, fish, poultry								90g/ 3X ▱					
14	BACON								1 rasher					
15	PROCESSED MEATS: e.g. Polony, salami								1 thin slice					
16	MEAT PIE/SAUSAGE ROLL								1X ◎ or 1 med					

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
17	MARGERINE/OIL/FAT IN PREPARATION (added to chicken/ beef/fish)								1 tsp					
18	EGGS (WITHOUT FAT): boiled/ poached								1 egg					
19	EGGS (WITH FAT): scrambled/ baked/ omelette								1 egg					
20	BREAD/ROLLS: white								1 roll or 1 med slice					
21	BREAD/ROLLS: brown								1 roll or 1 med slice					
22	BREAD/ROLLS: whole wheat/health								1 roll or 1 med slice					
23	PROVITA/ RYVITA								2 biscuits					
24	SPREAD: margarine/oil/ butter on bread/ rolls/ provita/ ryvita.								1 tsp					
25	PIZZA: commercial/ homemade								4 slices					
26	BREAKFAST CEREAL: high fibre e.g. All bran, highbulk, muesli, weet-bix, Pro-nutro								½ cup or 1 weet-bix or 1X◎					
27	BREAKFAST CEREAL: other e.g. cornflakes, rice crispies, special K								½ cup or 1X ◎					
28	OATS/OAT BRAN: cooked porridge								½ cup or 1X ◎					
29	MAIZE PORRIDGE: stiff/crumbled								½ cup or 1X ◎					
30	RICE: white								½ cup or 1X ◎					
31	RICE: brown								½ cup or 1X ◎					
32	MEALIE RICE/SAMP								½ cup or 1X ◎					
33	CORN: e.g. mealie, sweetcorn								½ cup/1 med/ 1X ◎					
34	POPCORN								1 cup or 2X ◎					
35	LEGUMES (tinned or dry beans) e.g. baked beans, lentils								½ cup or 1X ◎					
36	PASTA: e.g. Macaroni, spaghetti, noodles								1 cup or 2X ◎					
37	PASTA SAUCE: white or cheese sauce								½ cup					
38	POTATO: boiled, mashed, baked								½ cup or 1X ◎ or 1 med					

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
39	POTATO: roasted/fried in any fat/oil (includes french-fries/slap chips)								½ cup or 1X ◎ or 1 med					
40	MARGERINE/OIL/FAT IN PREPARATION: (added to pasta, potato, rice)								1 tsp					
41	FULL CREAM (FRESH/ POWDERED): milk, sour milk (Maas) on porridge/cereal or to drink (excluding milk blends)								½ cup or ½ std glass					
42	LOW FAT (FRESH/ POWDERED): milk, sour milk (Maas) on porridge/cereal or to drink (excluding milk blends)								½ cup or ½ std glass					
43	SKIMMED (FRESH/ POWDERED): milk, sour milk (Maas) on porridge/cereal or to drink (excluding milk blends)								½ cup or ½ std glass					
44	MILK IN TEA/COFFEE: full cream/low fat/skimmed								3 Tbs					
45	COFFEE CREAMER IN TEA/COFFEE: e.g. Cremora								1 tsp					
46	YOGHURT: full cream								½ cup or single serving					
47	YOGHURT: low fat								½ cup or single serving					
48	YOGHURT: fat free								½ cup or single serving					
49	DRINKING YOGHURT								½ cup or single serving					
50	FLAVOURED MILK DRINKS: milo, nesquick, horlicks, sterri-stumpie								½ cup					
51	ICE-CREAMS (DAIRY): ice-cream, milkshakes, smoothies, frozen yoghurt								1 cup					
52	ICE-CREAM (NON-DAIRY): sorbet, milkshakes, smoothies								1 cup					
53	SMOOTHIES (WITHOUT ICE-CREAM): fruit and ice blend only								1 cup					

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
54	CUSTARD, MILK PUDDINGS								½ cup					
55	CHEESE: on bread or in dishes (excluding cottage/cream cheese)								1 slice or 1X ▭					
56	CHEESE SPREAD (COTTAGE CHEESE)								1 Tbs					
57	CHEESE SPREAD (CREAM CHEESE)								1 Tbs					
58	REGULAR SALAD DRESSING/ MAYONNAISE								1 Tbs					
59	LOW FAT/LIGHT SALAD DRESSING/ MAYONNAISE								1 Tbs					
60	SAUCES: tomato, chutney, mustard, sweet chilli								1 Tbs					
61	PEANUT BUTTER:								1 Tbs					
62	PEANUTS:								30g or 1X ▭					
63	OTHER NUTS:								30g or 1X ▭					
64	RAISINS:								30g or 1X ▭					
65	OTHER DRIED FRUIT:								30g or 1X ▭					
66	CITRUS FRUIT: e.g. Oranges, grapefruit, naartjies, minolas etc.*								1 med or 1X ●					
67	APPLES/PEARS:								1 med or 1X ●					
68	BANANAS:								1 med or 1X ●					
69	PEACH/APRICOT:*								1 med or 1X ●					
70	WATERMELON/ SWEET MELON:*								1 large slice					
71	GUAVAS:*								1 med or 1X ●					
72	MANGO/ PAW-PAW/ PINEAPPLE:*								1 large slice					
73	GRAPES:*								8-10 grapes					
74	STRAWBERRIES:*								½ cup or 1X ◎					
75	AVOCADO:*								½ med					
76	FRUIT SALAD: tinned/ fresh								½ cup or 1X ◎					

*IF A PARTICULAR FRUIT WAS NOT IN SEASON DURING YOUR LAST MONTH OF TRAINING, YOU CAN MARK THE 'NO' COLUMN.

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
77	CABBAGE: (raw/ cooked)								½ cup or 1X ◎					
78	BROCCOLI, CAULIFLOWER, BRUSSEL SPROUTS: (raw/cooked)								½ cup or 1X ◎					
79	SPINACH/MAROG/ IMIFINO: (raw/ cooked)								½ cup or 1X ◎					
80	CARROTS (raw/cooked)								½ cup					
81	BEETROOT:								½ cup or 1X ◎					
82	TOMATO: (raw/cooked)								½ cup or 1X ◎					
83	ONIONS: (raw/cooked)								½ cup or 1X ◎					
84	TOMATO AND ONION: stewed								½ cup or 1X ◎					
85	GREEN PEAS: (raw/ cooked)								½ cup or 1X ◎					
86	GREEN BEANS: (raw/ cooked)								½ cup or 1X ◎					
87	MIXED VEGETABLES: carrots, peas, mealies, beans (in any combination)								½ cup or 1X ◎					
88	PUMPKIN, HUBBARD, BUTTERNUT								½ cup or 1X ◎					
89	GEM SQUASH, MARROWS, PATTY-PANS								1 med/ ½ cup or 1X ◎					
90	MIXED SALAD: lettuce, cucumber, tomato, peppers, onions in any combination								½ cup or 1X ◎					
91	SWEET POTATOES:								1 med/ 1/2 cup or 1X ◎					
92	MARGERINE/OIL/FAT IN PREPARATION: (added to vegetables)								1 tsp					
93	SUGAR: (white and/or brown added to vegetables)								1 tsp (heaped)					
94	MUFFIN/SCONE (bran, whole wheat only)								1 med or 1X ●					
95	MUFFIN/SCONE (all other) chocolate/ poppy-seed etc								1 med or 1X ●					
96	RUSKS: any								1 med or 2X ▭					

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
97	VETKOEK, DOUGHNUTS, SAMOOSAS, KOEKSISTER								1 med or 1X ◎					
98	ICED CAKES, TARTS, COOKIES with filling								1 med piece or 2 cookies or 1X ◎					
99	CAKE: commercial, homemade cakes/ tarts								1 med piece or 2 cookies or 1X ◎					
100	JAM/SYRUP/HONEY								1 tsp					
101	SWEETS: boiled sweets, jellies, toffee								4 sweets					
102	SWEETS: super C's, energy sweets								4 sweets					
103	CHOCOLATE								1 small bar/2-3 blocks					
104	ENERGY/HEALTH/ BREAKFAST BARS								1 small bar					
105	TEA NORMAL (excluding rooibos)								1 cup					
106	TEA ROOIBOS								1 cup					
107	COFFEE: instant/ground (excluding decaffeinated)								1 cup					
108	COFFEE: decaffeinated								1 cup					
109	SUGAR: (white & brown in tea/coffee)								1 tsp (heaped)					
110	ORANGE/GUAVA JUICE								1 std glass					
111	OTHER FRUIT JUICE								1 std glass					
112	MIXED JUICES/ CORDIALS : e.g. Oros, powdered mixes etc								1 std glass					
113	ENERGY DRINKS: Energade, Powerade etc								500ml					
114	CAFIENATTED ENERGY DRINKS: Red-Bull, Play etc.								250ml or 1 Tin					
115	WINE: red/white								1 wine glass or ± 200ml					
116	PORT/SHERRY/ LEQUEUR etc.								1 sherry glass					
117	REGULAR BEER/ CIDERS/COOLERS								340ml (1X can/ bottle)					

		NO	1-3 per month	1-3 per week	4-6 per week	1 per day	2 per day	3 or more per day	Std portion	1X std	½ X std	1½ X std	2X std	3X std
118	LIGHT BEER/ CIDERS/COOLERS								340ml (1X can/ bottle)					
119	SPIRITS: brandy, whiskey,rum,vodka,gin								1 tot/ shot					
120	NON-DIET FIZZY SOFT DRINKS: coke, fanta								1 std glass/can					
121	DIET FIZZY DRINKS: e.g. Coke zero, coke light, sprite zero etc.								1 std glass/can					
122	OTHER SOFT DRINKS OR FIZZY FRUIT SQUASH								1 std glass/can					
123	SALTY CRISPS: Simba chips, Lays etc.								1 small packet					
124	SALTY BISCUITS: Salty Cracks etc.								2 biscuits					

Appendix L

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

Participant Health and Lifestyle Questionnaire

Personal details:

1. Date of Birth: YYYY / MM / DD

2. Gender:

Female		Male	

3. Marital Status (mark 1 option only)

Single (never married)	Married	Divorced	Widowed	Living Together

4. Ethnicity

Black (African)	White	Coloured	Indian	Other

5. Highest level of education (mark 1 option only)

No formal education	
Primary school	
Secondary school	
University degree/Technical University Degree	
Technical University/College diploma	
Post-graduate degree	

Other	

6. Town/ City of residence: ----------

7. Occupation (work, includes housewife/man): ----------

8. Do you currently smoke cigarettes (mark 1 option only)?

Yes, daily	Yes, occasionally	No

9. Has any health worker or doctor ever told you that you had or have any one of the following (mark each option with a YES or NO)?

High blood pressure		High blood cholesterol		Diabetes mellitus		Heart disease		Arthritis		Other	
Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No

Weight history

10. What do you weigh at the moment? ---------- kg

11. What is your height? ---------- m

12. What is the maximum weight that you have ever weighed ---------- kg
(for females: excluding during pregnancy)?

13. How old were you when you were at this maximum weight? ---------- years

14. How long did you maintain this maximum weight (mark 1 option only)?

< 1 months	1- 6 months	> 6 months

kg

15. After the age of 18, what was the minimum you ever weighed? ----------

16. After the age of 18, what was the weight that you were able to maintain for the longest period of time? kg
----------.

17. How long was this period (mark 1 option only)?

< 1 months	1- 6 months	> 6 months

18. Would you describe your weight during most of your childhood years (ages 2 to 10) as

Underweight	Normal weight	Overweight

19. Would you describe your weight during most of your adolescent years (ages 11 to 19) as

Underweight	Normal weight	Overweight

20. When you look at yourself now, do you feel you are

Too Thin	Just about the right weight	Too chubby/fat

21. Which of the following describes you best at the moment (mark 1 option only)?

I am completely satisfied with my current weight	
I would like to gain some weight	
I would like to lose 1-5kg	
I would like to lose 6-10kg	
I would like to lose more than 10kg	

22. How satisfied are you with the following body parts (mark 1 option in each row)?

	Extremely Satisfied	Fairly satisfied	Undecided	Fairly dissatisfied	Extremely dissatisfied
Weight					

Waist					
Hips					
Calves					
Thighs					
Stomach					
Arms					

23. How often do you think of the following (mark 1 option in each row)?

	Almost never	Sometimes	Often	Almost always
I think about being thinner				
I am worried about gaining weight				
I think about needing to build more muscle				

24. How often do you weigh yourself (mark 1 option only)?

More than once a day	Once a day	Once or more per week, but not daily	Less than once a week

25. Have you tried to lose weight in the past 2 years?

Yes		No	

If NO, go to question 28

26. IF YES, what was the main reason (mark 1 option only)?

Performance improvement	
Aesthetics (to look good)	
Performance and aesthetics	

27. IF YES, have you done any of the following to lose weight in the past 2 years (mark each option with YES or NO)?

	Yes	No
Exercise		
Ate more fruit and vegetables		
Ate less high-fat food		
Ate less sweets and/or fizzy drinks		
Fasted		
Ate very little food		
Used food substitutes e.g. shakes		
Skipped meals		
Smoked cigarettes		
Used laxatives		
Took diet pills and or herbal mixes		
Made yourself vomit		
Used diuretics		

28. Have you tried to build/gain muscles in the past 2 years?

Yes		No	

If NO, go to question 30

29. IF YES, have you done any of the following to build/gain muscle in the past 2 years (mark each option with YES or NO)?

	Yes	No
Exercise (resistance and/or strength)		
Increased protein intake (from food)		
Used vitamin or mineral supplements		
Used protein or amino acid supplements		
Used creatine supplements		
Used anephedrine containing supplements		
Used anabolic steroids		

Gynaecological history: Women only, Men go to question 35

30. At what age did you start menstruating/bleeding? ---------- years

31. In the past year, on average, how many menstrual cycles have you had? ---------- cycles

32. Are you using any of the following for contraception or for your skin (mark 1 option only)?

Oral contraceptive (any type)	Birth control injection	Not one of these 2 options

33. If you do you use the pill or injection, for how long have you been using it? ---------- years
(OR ---------- months if less than a year)

34. How many full term pregnancies have you had? ---------- pregnancies

Exercise/ sport participation

35. As a marathon runner, do you see yourself as (mark 1 option only):

An elite and competitive runner	
A recreational but competitive runner	
A recreational but not competitive runner	

36. For how many years have you been doing marathon running: ---------- years

37. What is your MAIN reason for running (mark 1 option only)?
(This can be a difficult question, however it is important to mark only 1 option)

For health reasons	
For the competitive aspect	
For the enjoyment	
For weight management (to lose weight or keep your weight stable)	

For the social interaction	
Other	

38. On average, how many days do you run per week: ---------- days/ week

39. On average, how many hours do you run per training session ---------- hrs/day

40. In total, how many hours do you run per week: ---------- hrs/week

41. What is your average weekly training distance: ---------- km/week

42. How long have you maintained this distance: ---------- years ---------- months

43. What is your longest single training run per week? ---------- km/week

44. What has been your maximum weekly training distance: ---------- km/week

45. In how many marathons (≥42.2km) have you participated? ---------- marathon

46. What is the average time it takes you to complete a marathon (42.2km)? --------- hrs

47. Do you participate in any other sport/exercise on a weekly basis?

Examples: Jogging, aerobic dance/step, dancing, swimming, martial art, skating, cycling, volleyball, walking, strength/resistance training, squash, hiking, badminton, rock climbing, hockey, netball, tennis, football/soccer, golf, rugby, canoeing

Yes		No	

IF NO, go to question 49

48. IF YES, please complete the following table regarding participation in any other sport/exercise.

Type of sport	Number of sessions per week	Duration of each session

Food Intake Information

49. How many times during the week do you eat (never = 0; or else mention how many times per week) (complete each of the 6 options):

Breakfast	Mid-morning snack	Lunch	Afternoon snack	Dinner	After dinner snack

50. Which one of the following spreads do you usually use on bread, in porridge or in food preparation (mark 1 option only)?

Not one, do not use a spread on bread, in porridge or in cooking	
Butter	
Full fat hard margarine	
Low-med fat hard margarine	
Full fat soft margarine	
Low-med fat soft margarine	
Other e.g. lard, tallow	

51. Which one of the following oils do you usually use in food preparation (mark 1 option only)?

Not one, do not use oil in cooking	Sunflower oil	Canola oil	Olive oil	Other

52. In the past year, have you ever eaten so much food in a short period of time that you would be embarrassed if others saw you?

Yes		No	

IF NO, go to question 54

53. IF YES, during the times when you ate this way did you feel you couldn't stop eating or control what or how much you were eating?

Yes		No	

54. When you think about the food that you eat, do you think about the following (mark 1 option in each row):

	Almost never	Sometimes	Often	Almost always
How healthy the food is				
How much energy the food contains				
How unhealthy the food is				
How comforting the food is				
How rewarding/nice the food is to eat				

Total energy Intake

55. Do you restrict your total Calorie/Kilojoule (KCal/kJ) intake to manage your weight to improve your performance?

Yes		No	

If NO, go to question 57

56. If YES (you do restrict your KCal/kJ intake to improve your performance):

56.1 When do you usually restrict your KCal/kJ intake (mark 1 option only)?

Long-term (most of the time)	
During training	
Just prior to an event	

56.2 How do you limit your KCal/kJ intake (mark each line with No or Yes)

	No	Yes
I reduce my carbohydrate intake		
I reduce my fat intake		
I reduce my protein intake		

56.3 How effective do you feel KCal/kJ restriction is in improving your performance (mark 1 option only)?

Not at all	A little bit	Effective	Very effective

Carbo-loading (increasing carbohydrate intake)

57. Do you carbo-load to improve your performance?

Yes		No	

IF NO, go to question 59

58. IF YES (you do carbo-load to improve your performance):

58.1 When do you usually start carbo-loading (mark 1 option only)?

1 week before the event	
2-3 days before the event	
1 day before the event	

58.2 Which of the following sources of carbohydrates did you use to carbo-load for the LAST marathon/ultra marathon that you completed? (Mark each option with No or Yes)

	No	Yes
White bread		
Brown bread		
Other bread		
Pasta (any type)		
White rice		
Brown rice		
Potatoes		
Porridge/ pap (maize)		
Porridge: oats		
Instant Breakfast cereals e.g. All bran, weetbix, rice crispies, frosties etc.		
Carbohydrate containing sports drinks		
Sweets		
58.2 continued…	No	Yes
Fruit		
Pizza		
Pies		
Crisps		
Slap chips		
Cakes/muffins/biscuits		
Supplements (carbohydrate containing)		

58.3 Do you change other parts of your diet while carbo-loading?

Yes		No	

58.4 If YES to 58.3; what do you change (mark each item as either No or Yes)

	No	Yes
I increase my fat intake		
I decrease my fat intake		
I increase my protein intake		
I decrease my protein intake		

58.5 Do you practice carbo-depletion before carbo-loading?

Yes		No	

58.6 How effective do you feel carbo-loading is in improving your performance?

Not at all	A little bit	Effective	Very effective

Fat loading (increasing your fat intake)

59. Do you fat-load to improve your performance?

Yes		No	

IF NO, go to question 61

60. IF YES (you do fat-load to improve your performance):

60.1 When do you usually start fat-loading (mark 1 option only)?

1 week before the event	
2-3 days before the event	
1 day before the event	

60.2 Which of the following sources of fat do you use to fat-load (Mark each item as either No or Yes)

	No	Yes
Fried foods (slap chips, doughnuts, fish/chicken fried in batter etc.		
Margarine		
Butter		
Sunflower oil		
Olive oil		
Mayonnaise		
Avocado pear		
Nuts		

Crisps e.g. Simba/Willards chips, Niknaks etc.		
Chocolate		
Full fat dairy products (milk, yoghurt)		
Cheese		
Other		

60.3 Do you change other parts of your diet while fat-loading?

Yes		No	

60.4 If YES to 60.3; what do you change (mark each item as either No or Yes)

	No	Yes
I increase my carbohydrate intake		
I decrease my carbohydrate intake		
I increase my protein intake		
I decrease my protein intake		

60.5 How effective do you feel fat-loading is in improving your performance?

Not at all	A little bit	Effective	Very effective

Fat restriction (reduced fat intake)

61. Do you restrict your fat intake for any reason?

Yes		No	

IF NO, go to question 63

62. If YES, (you do restrict fat intake)

62.1 What is the main reason why you restrict fat intake (mark 1 option only)

For health reasons	
To control my weight	
To improve my performance	

Other	

62.2 What do you do to restrict your fat intake (mark each item as either No or Yes)

	No	Yes
Use low fat or fat free dairy products (milk, yoghurt, cottage cheese)		
Cut out fatty foods (e.g. fried foods, chips, skin of chicken)		
Cut out spreads e.g. butter or margarine on bread		
Use no or little fat in cooking		
Other		

62.3 How effective do you feel fat-restriction is in improving your performance?

Not at all	A little bit	Effective	Very effective

Protein intake

63. Do you increase your protein intake for any reason?

Yes		No	

IF NO, go to question 65

64. If YES, (you do increase your protein intake):

64.1 Why do you increase your protein intake (mark 1 option only)

To improve your performance	
To increase your muscle mass	
To prevent muscle breakdown	
To repair damaged muscle	
Other reason	

64.2 When do you increase your protein intake (mark each item as either No or Yes)

	No	Yes
During training		
1 week before the event		
2-3 days before the event		
1 day before the event		
During recovery after an event		
Other		

64.3 Which of the following do you eat/use to increase your protein intake (Mark each option as No or Yes):

	No	Yes
Red meat: beef, mutton, pork		
Chicken, turkey		
Ostrich		
Fish		
Legumes (beans, lentils)		
Soya products		
Dairy products (milk, yoghurt)		
Cheese		
Eggs		
Protein supplements		

64.4 How effective do you feel increased protein intake is in improving your performance?

Not at all	A little bit	Effective	Very effective

Fluid intake (hydration)

65. Do you control OR are you concerned about your fluid intake/hydration (mark 1 option in each row)

	Almost never	Sometimes	Often	Almost always
During training?				
24 hours prior to a race/event?				
During an event?				
During recovery?				

66. Indicate the 1 most important reason for fluid intake during the specified times (mark 1 option per row):

	I drink to thirst	I drink as much as tolerable	I drink according to predetermined fluid intake schedule
During training			
24hrs prior to a race/event			
During event			
During recovery			

67. What is the main reason for drinking a particular drink/fluid during a race (mark only 1 option per drink)?

	Never use	Thirst	Replace Fluid	Provide Energy	Other
Water					
Sports drink					
Coke/pepsi					
Other					

68. What would your usual total fluid intake during a marathon (42.2km) race be?

Salt intake

69. Do you increase your salt intake (mark each row with No or Yes)

	No	Yes
Before training?		
After training?		
Just before an event?		
During an event?		
Just after an event?		
During recovery after an event?		

If NO to all these options, go to question 71

70. If YES to any of the options in question 69

71.1 What is the MAIN reason why you increase your salt intake? (mark 1 option only)

To replace salt losses	
To prevent muscle cramps	
To assist with rehydration	
To promote glucose absorption	
To prevent low sodium levels (hyponatreamia)	
Other reason	

71.2 Which ONE of the following would you usually do to increase your salt intake? (mark 1 option only)

Take a salt supplement (pill)	
Drink a sports drink	

Eat more salty foods	
Add more salt while cooking/preparing food	
Add more salt to food at the table	
Other	

Appendix M

Exploring the Dietary Habits of South African Marathon Runners Over the Past Decade – An Observational and Descriptive Study on the Energy and Macronutrient Intake and CHO/Fat-loading strategies used in Preparation for a Marathon.

2024 Adult Compendium of Physical Activity

2024 Adult Compendium of Physical Activities

Major Heading	Activity Code	MET Value	Activity Description
Bicycling	01003	14.0	Bicycling, mountain, uphill, vigorous
Bicycling	01004	16.0	Bicycling, mountain, competitive racing
Bicycling	01008	8.5	Bicycling, BMX
Bicycling	01009	8.5	Bicycling, mountain, general
Bicycling	01010	4.0	Bicycling, <10 mph, leisure, to work or for pleasure (Taylor Code 115)
Bicycling	01011	6.8	Bicycling, to/from work, self selected pace
Bicycling	01013	5.8	Bicycling, on dirt or farm road, moderate pace
Bicycling	01014	7.0	Bicycling, general
Bicycling	01015	4.3	Bicycling, self-selected easy pace
Bicycling	01016	7.0	Bicycling, self-selected moderate pace
Bicycling	01017	9.0	Bicycling, self-selected vigorous pace
Bicycling	01018	3.5	Bicycling, leisure 5.5 mph
Bicycling	01019	5.8	Bicycling, leisure, 9.4 mph
Bicycling	01020	6.8	Bicycling, 10-11.9 mph, leisure, slow, light effort
Bicycling	01030	8.0	Bicycling, 12-13.9 mph, leisure, moderate effort
Bicycling	01040	10.0	Bicycling, 14-15.9 mph, racing or leisure, fast, vigorous effort
Bicycling	01050	12.0	Bicycling, 16-19 mph, racing/not drafting or >19 mph drafting, very fast, racing general
Bicycling	01060	16.8	Bicycling, >20 mph, racing, not drafting
Bicycling	01065	8.5	Bicycling, 12 mph, seated, hands on brake hoods or bar drops, 80 rpm
Bicycling	01066	9.0	Bicycling, 12 mph, standing, hands on brake hoods, 60 rpm
Bicycling	01070	5.0	Unicycling
Bicycling	01080	6.8	E-bike (electrically assisted) without electronic support
Bicycling	01084	6.0	E-bike (electrically assisted) with light electronic support
Bicycling	01088	4.0	E-bike (electrically assisted) with high electronic support
Bicycling	01200	6.8	Bicycling, stationary, general
Bicycling	01210	3.5	Bicycling, stationary, 25-30 watts, very light to light effort
Bicycling	01214	4.0	Bicycling, stationary, 50 watts, light effort
Bicycling	01216	5.0	Bicycling, stationary, 60 watts, light to moderate effort
Bicycling	01218	5.8	Bicycling, stationary, 70-80 watts
Bicycling	01220	6.0	Bicycling, stationary, 90-100 watts, moderate to vigorous
Bicycling	01224	6.8	Bicycling, stationary, 101-125 watts
Bicycling	01228	8.0	Bicycling, stationary, 126-150 watts
Bicycling	01232	10.3	Bicycling, stationary, 151-199 watts
Bicycling	01236	10.8	Bicycling, stationary, 200-229 watts, vigorous
Bicycling	01240	12.5	Bicycling, stationary, 230-250 watts, very vigorous
Bicycling	01244	13.8	Bicycling, stationary, 270-305 watts, very vigorous
Bicycling	01248	16.3	Bicycling, stationary, >325 watts, very vigorous
Bicycling	01252	5.5	Bicycling, concentric only, 100 W
Bicycling	01254	11.0	Bicycling, concentric only, 200 W
Bicycling	01262	2.3	Bicycling, eccentric only, 100 to 149 W
Bicycling	01264	4.0	Bicycling, eccentric only, 200 W

Conditioning Exercise	02074	14.0	Rowing, stationary, ≥ 200 watts, very vigorous effort
Conditioning Exercise	02078	11.0	Shuttle running, forward/backward/lateral
Conditioning Exercise	02080	6.8	Ski machine, general
Conditioning Exercise	02082	10.5	Ski ergometer, cross country, double poling, slow to moderate speed
Conditioning Exercise	02084	18.0	Ski ergometer, cross country, double poling, fast to maximum speed
Conditioning Exercise	02085	10.5	Slide board exercise, general
Conditioning Exercise	02090	6.0	Slimnastics, jazzercise
Conditioning Exercise	02101	2.3	Stretching, mild
Conditioning Exercise	02103	1.8	Pilates, traditional, mat
Conditioning Exercise	02105	2.8	Pilates, general
Conditioning Exercise	02107	8.5	Pound, combination of Pilates and body movements with drumming
Conditioning Exercise	02108	4.5	Pole dancing, exercise class
Conditioning Exercise	02110	6.8	Teaching exercise classes (e.g., aerobic, water)
Conditioning Exercise	02112	2.8	Therapeutic exercise ball, Fitball exercise
Conditioning Exercise	02114	9.5	Therapeutic exercise ball, Fitball exercise, high intensity
Conditioning Exercise	02115	2.8	Upper body exercise, arm ergometer, general, light
Conditioning Exercise	02116	2.0	Arm Ergometer, hand bike, 15W
Conditioning Exercise	02117	2.8	Arm Ergometer, hand bike, 25-30W
Conditioning Exercise	02118	3.5	Arm Ergometer, hand bike, 45W
Conditioning Exercise	02119	4.3	Upper body exercise, stationary bicycle - Airdyne (arms only) 40 rpm, moderate intensity
Conditioning Exercise	02120	5.3	Water aerobics, water calisthenics, water exercise
Conditioning Exercise	02135	1.3	Whirlpool, sitting
Conditioning Exercise	02140	2.5	Video, exercise workouts, TV conditioning programs (e.g., yoga, stretching, seated), light effort
Conditioning Exercise	02143	4.0	Video, exercise workouts, TV conditioning programs (e.g., cardio-resistance training), moderate
Conditioning Exercise	02145	6.0	Video, exercise workouts, TV conditioning programs (e.g., cardio-resistance training), vigorous
Conditioning Exercise	02150	2.3	Yoga, Hatha
Conditioning Exercise	02153	8.0	Yoga, Hatha, high intensity
Conditioning Exercise	02155	3.0	Yoga, Hot
Conditioning Exercise	02160	4.0	Yoga, Power
Conditioning Exercise	02170	2.0	Yoga, Nadisodhana
Conditioning Exercise	02175	2.3	Yoga, General
Conditioning Exercise	02180	3.5	Yoga, Surya Namaskar
Conditioning Exercise	02185	2.7	Yoga, Vinyasa
Conditioning Exercise	02200	5.3	Native New Zealander PA, (e.g., Haka Powhiri, Poi, Moteatea, etc.), general moderate effort
Conditioning Exercise	02205	6.8	Native New Zealander PA, general, vigorous effort
Conditioning Exercise	02210	7.0	High intensity interval exercise, moderate effort
Conditioning Exercise	02214	11.0	High intensity interval exercise, burpees, mountain climbers, squat jumps, Tabata, vigorous effort
Conditioning Exercise	02225	2.3	Balance Exercise Assist Robot (BEAR), simulated skiing, tennis, rodeo
Conditioning Exercise	02230	5.8	Hooping (formerly known as hula® hooping)
Conditioning Exercise	02240	9.0	Impulse Training System, Inertial Exercise Trainer
Conditioning Exercise	02280	7.9	Virtual Reality Fitness, Supernatural™ "Flow", "Boxing" vigorous intensity
Conditioning Exercise	02284	9.3	ExerCube, workout series
Conditioning Exercise	02288	13.0	Blackbox Immersive virtual reality exergaming system, vigorous intensity
Bicycling	01270	9.0	Bicycling, stationary, RPM/Spin bike class
Bicycling	01290	8.8	Bicycling, interactive virtual cycling, indoor cycle ergometer
Bicycling	01305	8.8	Bicycling, high intensity interval training
Conditioning Exercise	02000	7.3	Aerobic, general
Conditioning Exercise	02001	5.5	Aerobic, step, with 4-inch step
Conditioning Exercise	02002	7.3	Aerobic, step, with 6 – 8 inch step
Conditioning Exercise	02003	9.0	Aerobic, step, with 10 – 12 inch step
Conditioning Exercise	02004	7.8	Bench step class, general
Conditioning Exercise	02005	4.8	Aerobic dance, low impact, moderate effort
Conditioning Exercise	02006	8.0	Aerobic dance, high impact, vigorous effort
Conditioning Exercise	02007	10.0	Aerobic dance wearing 10-15 lb weights
Conditioning Exercise	02008	5.0	Army type obstacle course exercise, boot camp training program
Conditioning Exercise	02020	7.5	Calisthenics (e.g., pushups, sit ups, pull-ups, jumping jacks, burpees, battling ropes), vigorous effort
Conditioning Exercise	02022	3.8	Calisthenics (e.g., pushups, sit ups, pull-ups, lunges), moderate effort
Conditioning Exercise	02024	2.8	Calisthenics (e.g., curl ups, abdominal crunches, plank), light effort
Conditioning Exercise	02030	3.5	Calisthenics, light or moderate effort, general (e.g., back exercises), going up & down from floor (Taylor Code 150)
Conditioning Exercise	02032	6.0	Circuit training, body weight exercises
Conditioning Exercise	02034	3.5	Circuit training, light effort
Conditioning Exercise	02035	5.0	Circuit training, moderate effort
Conditioning Exercise	02040	7.5	Circuit training, including kettlebells, some aerobic movement with minimal rest, general, vigorous intensity
Conditioning Exercise	02045	3.5	Curves™ exercise routines in women
Conditioning Exercise	02048	5.0	Elliptical trainer, moderate effort
Conditioning Exercise	02049	9.0	Elliptical trainer, vigorous effort
Conditioning Exercise	02050	6.0	Resistance (weight lifting - free weight, nautilus or universal-type), power lifting or body building, vigorous effort (Taylor Code 210)
Conditioning Exercise	02052	5.0	Resistance (weight) training, squats, deadlift, slow or explosive effort
Conditioning Exercise	02054	3.5	Resistance (weight) training, multiple exercises, 8-15 reps at varied resistance
Conditioning Exercise	02055	5.8	Resistance Training, circuit, reciprocol supersets, peripheral hear action training
Conditioning Exercise	02056	3.0	Body weight resistance exercises (e.g., squat, lunge, push-up, crunch), general
Conditioning Exercise	02057	6.5	Body weight resistance exercises (e.g., squat, lunge, push-up, crunch), high intensity
Conditioning Exercise	02058	9.8	Kettle bell swings
Conditioning Exercise	02060	5.5	Health club exercise, general (Taylor Code 160)
Conditioning Exercise	02061	5.0	Health club exercise classes general, gym/weight training combined in one visit
Conditioning Exercise	02062	7.8	Health club exercise, conditioning classes
Conditioning Exercise	02064	3.8	Home exercise, general
Conditioning Exercise	02065	9.3	Stair treadmill ergometer, general
Conditioning Exercise	02068	11.0	Rope skipping exercise, general
Conditioning Exercise	02069	9.0	Jumping rope, Digi-Jump Maching, 120 jumps/minute
Conditioning Exercise	02070	7.3	Rowing, stationary ergometer, general, vigorous effort
Conditioning Exercise	02071	5.0	Rowing, stationary ergometer, general, <100 watts, moderate effort
Conditioning Exercise	02072	7.5	Rowing, stationary, 100 to 149 watts, vigorous effort
Conditioning Exercise	02073	11.0	Rowing, stationary, 150 to 199 watts, vigorous effort

Fishing & Hunting	04010	4.3	Fishing related, digging worms, with shovel
Fishing & Hunting	04020	4.0	Fishing from river bank and walking
Fishing & Hunting	04030	2.0	Fishing from boat or canoe, sitting
Fishing & Hunting	04040	3.5	Fishing from river bank, standing (Taylor Code 660)
Fishing & Hunting	04050	6.0	Fishing in stream, in waders (Taylor Code 670)
Fishing & Hunting	04060	2.0	Fishing, ice, sitting
Fishing & Hunting	04061	1.8	Fishing, jig or line, standing, general
Fishing & Hunting	04062	3.5	Fishing, dip net, setting net and retrieving fish, general
Fishing & Hunting	04063	3.8	Fishing, set net, setting net and retrieving fish, general
Fishing & Hunting	04064	3.0	Fishing, fishing wheel, setting net and retrieving fish, general
Fishing & Hunting	04065	2.3	Fishing with a spear, standing
Fishing & Hunting	04070	2.5	Hunting, bow and arrow or crossbow
Fishing & Hunting	04080	6.0	Hunting, deer, elk, large game (Taylor Code 170)
Fishing & Hunting	04081	9.8	Hunting large game, dragging carcass
Fishing & Hunting	04083	4.0	Hunting large marine animals
Fishing & Hunting	04085	2.5	Hunting, large game from a hunting stand, limited walking
Fishing & Hunting	04086	2.0	Hunting large game from a car, plane, or boat
Fishing & Hunting	04090	2.5	Hunting, duck, wading
Fishing & Hunting	04095	3.0	Hunting flying fox, squirrel
Fishing & Hunting	04100	5.0	Hunting, general
Fishing & Hunting	04110	6.0	Hunting, pheasants or grouse (Taylor Code 680)
Fishing & Hunting	04115	3.3	Hunting birds
Fishing & Hunting	04120	5.0	Hunting, rabbit, squirrel, prairie chick, raccoon, small game (Taylor Code 690)
Fishing & Hunting	04123	3.3	Hunting pigs, wild
Fishing & Hunting	04124	2.0	Trapping game, general
Fishing & Hunting	04125	9.5	Hunting - hiking with hunting gear
Fishing & Hunting	04130	2.5	Pistol shooting or trap shooting, standing
Fishing & Hunting	04140	2.3	Rifle exercises, shooting, lying down
Fishing & Hunting	04145	2.5	Rifle exercises, shooting, kneeling or standing
Fishing & Hunting	04150	2.8	Foraging, 0-9.9kg backpack
Fishing & Hunting	04152	3.0	Foraging, 10-15kg backpack
Fishing & Hunting	04160	1.0	Sitting in boat, passenger
Fishing & Hunting	04164	1.5	Standing in boat
Fishing & Hunting	04168	3.3	Activities in a boat, lifting, lowering
Home Activities	05010	3.3	Cleaning, sweeping carpet or floors, general
Home Activities	05011	2.3	Cleaning, sweeping, slow, light effort
Home Activities	05012	3.8	Cleaning, sweeping, fast, moderate effort
Home Activities	05020	3.5	Cleaning heavy or major (e.g., wash car, clean garage), moderate effort
Home Activities	05021	3.5	Cleaning, mopping, standing, moderate effort
Home Activities	05022	3.3	Cleaning windows, washing windows, general
Home Activities	05023	2.5	Mopping, standing, light effort
Home Activities	05024	4.5	Polishing floors, standing, walking slowly, using electric polishing machine
Home Activities	05025	2.8	Multiple household tasks all at once, light effort
Conditioning Exercise	02300	3.0	Wand exercise, Life-Build-Line
Conditioning Exercise	02310	6.5	Zumba, group class
Conditioning Exercise	02315	5.5	Zumba, home video
Conditioning Exercise	02340	2.8	Sit to stand exercise, 6-12 times/min
Conditioning Exercise	02344	4.0	Sit to stand exercise, 18-24 times/min
Dancing	03005	6.0	Afro-Cuban salsa (Cuban cha-cha-cha, mambo, Afro rumba, contratiempo son steps, orisha/santo movements)
Dancing	03010	5.0	Ballet, modern, or jazz general, rehearsal or class
Dancing	03011	6.3	Ballet exercises (plie, tendus, jetes, rond de jambes, fondus, grand battement, grand adage, sautes, temp Leve's)
Dancing	03012	6.8	Ballet, modern, or jazz, performance, vigorous effort
Dancing	03014	4.8	Tap
Dancing	03025	4.5	Ethnic or cultural dancing (e.g. Greek, Middle Eastern, hula, salsa, merengue, bamba y plena, flamenco, belly, and swing)
Dancing	03028	5.5	Chinese square dance, Ballet & Tibetan dance
Dancing	03029	7.3	Chinese square dance, aerobic dance
Dancing	03030	5.5	Ballroom dancing, fast (Taylor Code 125)
Dancing	03031	9.8	Nightclub or folk dancing, vigorous effort (e.g., nightclub, disco, folk, line dancing, Irish step dancing, polka, contra)
Dancing	03033	5.0	Folk dancing, moderate effort
Dancing	03038	11.3	Ballroom dancing, competitive, general
Dancing	03039	13.0	ballroom dance, DanceSport competition (modern waltz, tango, Viennese waltz, slow fox, quick step, samba, chacha, rumba, paso doble, jive)
Dancing	03040	3.0	Ballroom, slow, examples: waltz, foxtrot, slow dancing, samba tango, rumba, 19th century dance, mambo, cha cha
Dancing	03042	6.0	Ballroom Dance, Recreational (Waltz, Foxtrot, Cha-cha, Swing)
Dancing	03050	5.5	Anishinaabe Jingle dancing, brisk pace, other traditional American Indian dancing performed by women, moderate effort
Dancing	03060	3.5	Caribbean dance (Abakua, Beguine, Bellair, Bongo, Brukin's, Caribbean Quadrills, Dinki Mini, Gere, Gumbay, Ibo, Jonkonnu, Kumina, Oreisha, Jambu)
Dancing	03070	3.8	Contemporary dancing, general
Dancing	03072	4.3	Contemporary dancing, nightclub
Dancing	03075	8.5	Flamenco dance
Dancing	03078	4.5	Jazz dancing, general
Dancing	03080	10.3	Musical Theater, Singing/dancing
Dancing	03085	5.8	Polynesian dance, Hawaiian hula slow, Maori haka, Tongan
Dancing	03086	7.0	Polynesian dance, Hawaiian hula fast, Samoan sasa, Fijian style fast, Filipino Tinikling
Dancing	03087	8.8	Polynesian dance, Samoan slap, Tahitian
Dancing	03090	4.8	Salsa Dancing, with partner
Dancing	03091	6.3	Salsa dancing, to a video
Dancing	03093	5.5	Square Dancing, American Western, country
Fishing & Hunting	04001	3.5	Fishing, general
Fishing & Hunting	04005	4.5	Fishing, crab fishing
Fishing & Hunting	04007	4.0	Fishing, catching fish with hands

Home Activities	05146	3.8	Standing, packing/unpacking boxes, occasional lifting lightweight household items, loading or unloading items into a car, moderate effort
Home Activities	05147	3.0	Implied walking, putting away household items, moderate effort
Home Activities	05148	2.0	Watering plants
Home Activities	05149	2.5	Building a fire inside
Home Activities	05150	9.0	Moving household items upstairs, carrying boxes or furniture
Home Activities	05160	2.0	Standing, light effort tasks (pump gas, change light bulb, etc.)
Home Activities	05165	3.5	Walking, moderate effort tasks, non-cleaning (readying to leave, shut/lock doors, close windows, etc.
Home Activities	05170	2.3	Sitting, playing with child(ren), light effort, only active periods
Home Activities	05171	2.8	Standing, playing with child(ren), light effort, only active periods
Home Activities	05175	3.5	Walking/running, playing with child(ren), moderate effort, only active periods
Home Activities	05180	5.8	Walking/running, playing with child(ren), vigorous effort, only active periods
Home Activities	05181	3.0	Walking and carrying small child, child weighing 15 lbs or more
Home Activities	05182	2.5	Walking and carrying small child, child weighing less than 15 lbs
Home Activities	05183	2.0	Standing, holding child
Home Activities	05184	2.5	Child care, infant, general
Home Activities	05185	2.0	Child care: sitting or kneeling, dressing, bathing, grooming, feeding, occasional lifting of child-light effort, general
Home Activities	05186	3.5	Child care: standing, dressing, bathing, grooming, feeding, occasional lifting of child- light effort
Home Activities	05188	1.5	Reclining with baby
Home Activities	05189	2.0	Breastfeeding, sitting or reclining
Home Activities	05190	2.5	Sit, playing with animals, light, only active period
Home Activities	05191	2.8	Stand, playing with animals, light effort, only active periods
Home Activities	05192	2.8	Walk or run, playing with animals, general, light effort, only active periods
Home Activities	05193	4.0	Walk/run, playing with animals, moderate effort, only active periods
Home Activities	05194	5.0	Walk/run, playing with animals, vigorous effort, only active periods
Home Activities	05195	3.5	Standing, bathing dog
Home Activities	05197	2.3	Animal care, household animals, general
Home Activities	05200	3.0	Elder care, disabled adult, bathing, dressing, moving into and out of bed, only active periods
Home Activities	05205	1.8	Elder care, disabled adult, feeding, combing hair, light effort, only active periods
Home Activities	05300	1.3	Handwashing
Home Repair	06010	3.0	Airplane repair
Home Repair	06020	4.0	Automobile body work
Home Repair	06030	3.3	Automobile repair, light or moderate effort
Home Repair	06040	3.0	Carpentry, general, workshop (Taylor Code 620)
Home Repair	06050	6.0	Carpentry, outside house, (Taylor Code 640)
Home Repair	06052	3.8	Carpentry, outside house, building a fence
Home Repair	06060	3.3	Carpentry, finishing, varnishing, or refinishing cabinets or furniture
Home Repair	06070	6.0	Carpentry, sawing hardwood, planing and drilling wood, moderate-to-vigorous effort
Home Repair	06072	4.0	Carpentry, home remodeling tasks, moderate effort
Home Repair	06074	2.3	Carpentry, home remodeling tasks, light effort
Home Repair	06080	5.0	Caulking, chinking log cabin
Home Repair	06090	4.5	Caulking, except log cabin
Home Activities	05026	3.3	Multiple household tasks all at once, moderate effort
Home Activities	05027	4.3	Multiple household tasks all at once, vigorous effort
Home Activities	05030	3.3	Cleaning, house or cabin, general, moderate effort
Home Activities	05032	2.5	Dusting or polishing furniture, general
Home Activities	05035	3.3	Kitchen activity, general, (e.g., cooking, washing dishes, cleaning up) moderate effort
Home Activities	05040	2.5	Cleaning, general (straightening up, changing linen, carrying out trash), light effort
Home Activities	05041	2.0	Wash dishes, standing or in general (not broken into stand/walk components)
Home Activities	05042	2.0	Wash dishes, clearing dishes from table, walking, light effort
Home Activities	05043	3.0	Vacuuming, general, moderate effort
Home Activities	05044	3.0	Butchering animals, small
Home Activities	05045	6.0	Butchering animals, large, vigorous effort
Home Activities	05046	2.3	Cutting and smoking fish, drying fish or meat
Home Activities	05048	4.0	Tanning hides, general
Home Activities	05049	3.5	Cooking or food preparation, moderate effort
Home Activities	05050	2.0	Cooking or food preparation - standing or sitting or in general (not broken into stand/walk components), manual appliances, light effort
Home Activities	05051	2.3	Cooking or food preparation, walking
Home Activities	05052	2.3	Serving food, setting/cleaning table, implied walking or standing
Home Activities	05053	2.5	Feeding household animals
Home Activities	05054	3.5	carrying groceries, on level ground, walking
Home Activities	05055	2.5	Putting away groceries (e.g. carrying groceries, carrying packages)
Home Activities	05056	5.3	Carrying groceries upstairs
Home Activities	05057	3.0	Cooking Indian bread or other food on an outside stove
Home Activities	05060	3.3	Food shopping with or without a grocery cart; carrying a 10 lb bag; standing or walking
Home Activities	05065	2.3	Non-food shopping, with or without cart, standing or walking
Home Activities	05070	1.8	Ironing
Home Activities	05080	1.3	Knitting, sewing, light effort, wrapping presents, sitting
Home Activities	05082	2.8	Sewing with a machine
Home Activities	05090	2.3	Laundry, fold or hang clothes, put clothes in washer or dryer, packing suitcase, washing clothes by hand, implied standing, light effort
Home Activities	05091	2.0	Laundry, fold or hang clothes, sitting
Home Activities	05092	4.0	Laundry, moderate effort
Home Activities	05095	2.0	Laundry, putting away clothes, gathering clothes to pack, putting away laundry, implied walking
Home Activities	05100	3.0	Making bed, changing linens
Home Activities	05110	5.0	Maple syruping/sugar bushing (including carrying buckets, carrying wood)
Home Activities	05120	5.8	Moving furniture, household items, carrying boxes
Home Activities	05121	5.0	Moving, lifting light loads
Home Activities	05125	4.8	Organizing a room
Home Activities	05130	3.5	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, moderate effort
Home Activities	05131	2.0	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, light effort
Home Activities	05132	6.5	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, vigorous effort
Home Activities	05140	3.0	Sweeping garage, sidewalk, or outside house

Lawn & Garden	08010	5.5	Carrying, loading or stacking wood, loading/unloading or carrying lumber, moderate effort
Lawn & Garden	08019	4.5	Chopping wood, splitting logs, moderate effort
Lawn & Garden	08020	6.5	Chopping wood, splitting logs, vigorous effort
Lawn & Garden	08025	3.5	Clearing light brush, thinning garden, moderate effort
Lawn & Garden	08030	6.3	Clearing land, haul brush, undergrowth, or ground, vigorous effort
Lawn & Garden	08040	5.0	Digging sandbox, shoveling sand
Lawn & Garden	08045	3.5	Digging, spading, filling garden, composting, light-to-moderate effort
Lawn & Garden	08050	5.0	Digging, spading, filling garden, composting (Taylor Code 590)
Lawn & Garden	08052	7.3	Digging, spading, filling garden, composting, vigorous effort
Lawn & Garden	08055	2.8	Driving tractor
Lawn & Garden	08057	8.3	Felling trees, large size
Lawn & Garden	08058	5.3	Felling trees, small-medium size
Lawn & Garden	08060	5.8	Gardening with heavy power tools, using chain saw, tilling a garden
Lawn & Garden	08066	2.0	gardening, general
Lawn & Garden	08070	4.0	Irrigation channels, opening and closing ports
Lawn & Garden	08080	6.3	Laying crushed rock or gravel
Lawn & Garden	08090	5.0	Laying sod
Lawn & Garden	08095	5.5	Mowing lawn, general, walking, moderate effort
Lawn & Garden	08100	2.5	Mowing lawn, riding mower (Taylor Code 550)
Lawn & Garden	08110	6.0	Mowing lawn, hand mower, vigorous effort (Taylor Code 570)
Lawn & Garden	08120	5.0	Mowing lawn, walk, power mower, moderate or vigorous effort
Lawn & Garden	08125	4.5	Mowing lawn, power mower, light or moderate effort (Taylor Code 590)
Lawn & Garden	08130	2.5	Operating snow blower, walking
Lawn & Garden	08135	2.6	Planting, potting, transplanting seedlings or plants, light effort
Lawn & Garden	08140	4.3	Planting seedlings, shrubs, stooping, moderate effort
Lawn & Garden	08145	4.3	Planting crops or garden, stooping, moderate effort
Lawn & Garden	08150	4.5	Planting trees
Lawn & Garden	08160	4.0	Raking lawn or leaves, moderate effort
Lawn & Garden	08165	4.0	Raking lawn (Taylor Code 600)
Lawn & Garden	08170	4.0	Raking roof with snow rake
Lawn & Garden	08180	3.0	Riding snow blower
Lawn & Garden	08190	4.0	Sacking grass, leaves
Lawn & Garden	08192	5.5	Shoveling dirt or mud
Lawn & Garden	08195	5.3	Shoveling snow, by hand, moderate effort
Lawn & Garden	08200	6.0	Shoveling snow, by hand (Taylor Code 610)
Lawn & Garden	08202	7.5	Shoveling snow, by hand, vigorous effort
Lawn & Garden	08210	3.8	Trimming shrubs or trees, manual cutter
Lawn & Garden	08215	3.3	Trimming shrubs or trees, power cutter, using leaf blower, edger, moderate effort
Lawn & Garden	08220	3.0	Walking, applying fertilizer or seeding a lawn, push applicator
Lawn & Garden	08230	4.0	Watering lawn or garden, standing or walking
Lawn & Garden	08239	3.8	Weeding, cultivating garden, light-to-moderate effort
Lawn & Garden	08240	4.5	Weeding, cultivating garden, moderate effort (Taylor Code 580)
Lawn & Garden	08241	5.0	Weeding, cultivating garden, using hoe moderate-to-vigorous effort
Home Repair	06100	5.0	Cleaning gutters
Home Repair	06110	5.0	Excavating garage
Home Repair	06120	5.0	Hanging storm windows
Home Repair	06122	5.0	Hanging sheet rock inside house
Home Repair	06124	3.0	Hammering nails
Home Repair	06126	2.5	Home repair, general, light effort
Home Repair	06127	4.5	Home repair, general, moderate effort
Home Repair	06128	6.0	Home repair, general, vigorous effort
Home Repair	06130	4.5	Laying or removing carpet
Home Repair	06140	3.8	Laying tile or linoleum
Home Repair	06144	3.0	Repairing appliances
Home Repair	06150	5.0	Painting, outside home (Taylor Code 650)
Home Repair	06160	3.3	Painting inside house, wallpapering, scraping paint
Home Repair	06165	4.5	Painting (Taylor Code 630)
Home Repair	06167	3.0	Plumbing, general
Home Repair	06170	3.0	Put on and removal of tarp – sailboat
Home Repair	06180	6.0	Roofing
Home Repair	06190	4.5	Sanding floors with a power sander
Home Repair	06200	4.5	Scraping and painting sailboat or powerboat
Home Repair	06205	2.0	Sharpening tools
Home Repair	06210	5.0	Spreading dirt with a shovel
Home Repair	06220	4.5	Washing and waxing hull of sailboat or airplane
Home Repair	06225	2.0	Washing and waxing car
Home Repair	06230	4.5	Washing fence, painting fence, moderate effort
Home Repair	06240	3.3	Wiring, tapping-splicing
Inactivity	07009	1.0	Lying quietly and watching television
Inactivity	07011	1.0	Lying quietly, doing nothing, lying in bed awake, listening to music (not talking or reading)
Inactivity	07020	1.0	Sit, watch television
Inactivity	07021	1.0	Sitting quietly, general
Inactivity	07022	1.5	Sitting quietly, fidgeting, general, fidgeting hands
Inactivity	07023	1.8	Sitting, fidget feet
Inactivity	07024	1.3	Sitting smoking
Inactivity	07025	1.5	Sitting, listening to music (not talking or reading) or watching a movie in a theater
Inactivity	07026	1.3	Sitting at a desk, resting head in hands
Inactivity	07030	1.0	Sleeping
Inactivity	07040	1.3	Standing quietly (standing in a line)
Inactivity	07041	1.5	Standing (fidgeting)
Inactivity	07045	1.3	Standing watching television
Inactivity	07050	1.5	Reclining, writing
Inactivity	07060	1.3	Reclining, talking or talking on phone
Inactivity	07070	1.3	Reclining, reading
Inactivity	07075	1.0	Meditating
Lawn & Garden	08009	4.1	Carrying, loading or stacking wood, loading/unloading or carrying lumber, light-to- moderate effort

Music Playing	10040	3.8	Drums, sitting
Music Playing	10045	3.0	Drumming (e.g., bongo, conga, benbe), moderate, sitting
Music Playing	10048	8.3	Drumming, concert/live show
Music Playing	10050	2.0	Flute, sitting
Music Playing	10060	1.8	Horn, standing
Music Playing	10070	2.3	Piano, sitting
Music Playing	10074	2.0	Playing musical instruments, general
Music Playing	10077	2.0	Organ, sitting
Music Playing	10080	3.5	Trombone, standing
Music Playing	10090	2.5	Trumpet, standing
Music Playing	10100	2.5	Violin, sitting
Music Playing	10110	1.8	Woodwind instruments, sitting
Music Playing	10115	1.8	Brass instruments, sitting
Music Playing	10120	2.0	Guitar, classical, folk, sitting
Music Playing	10125	3.0	Guitar, rock and roll band, standing
Music Playing	10130	4.0	Marching band, baton twirling, walking, moderate pace, general
Music Playing	10131	5.5	Marching band, playing an instrument, walking, brisk pace, general
Music Playing	10135	3.5	Marching band, drum major, walking
Occupation	11000	2.0	Active workstation, Pedal desk, balance chair/ball, General, light effort
Occupation	11001	3.5	Active workstation, Pedal desk (40 watts)
Occupation	11002	5.3	Active workstation, Pedal desk (80 watts)
Occupation	11003	2.0	Active workstation, treadmill desk, walking slowly 1.0 mph or less
Occupation	11004	2.8	Active workstation, treadmill desk, walking 1.0 - 2.0 mph
Occupation	11006	3.0	Airline flight attendant
Occupation	11008	4.8	Apple Harvesting
Occupation	11010	4.0	Bakery, general, moderate effort
Occupation	11015	2.0	Bakery, light effort
Occupation	11020	2.3	Bookbinding
Occupation	11030	6.0	Building road, driving heavy machinery
Occupation	11035	2.0	Building road, directing traffic, standing
Occupation	11038	2.5	Carpentry, general, light effort
Occupation	11040	4.3	Carpentry, general, moderate effort
Occupation	11042	7.0	Carpentry, general, heavy or vigorous effort
Occupation	11050	8.0	Carrying heavy loads (e.g., bricks, tools)
Occupation	11060	8.0	Carrying moderate loads up stairs, moving boxes, 25-49 lbs
Occupation	11070	4.0	Chambermaid, hotel housekeeper, making bed, cleaning bathroom, pushing cart
Occupation	11072	4.3	Cleaning, vacuuming commercial space
Occupation	11080	5.3	Coal mining, drilling coal, rock
Occupation	11090	5.0	Coal mining, erecting supports
Occupation	11100	5.5	Coal mining, general
Occupation	11110	6.3	Coal mining, shoveling coal, by hand
Occupation	11115	2.5	Cook, chef
Occupation	11120	4.0	Construction, outside, remodeling, new structures (e.g., roof repair, miscellaneous)
Lawn & Garden	08245	3.8	Gardening, general, moderate effort
Lawn & Garden	08246	3.5	Picking fruit or coffee from trees, moderate effort
Lawn & Garden	08248	4.5	Harvesting Produce, Picking fruit off trees, gleaning fruits, picking fruits/vegetables, climbing ladder to pick fruit, vigorous effort
Lawn & Garden	08250	3.0	Implied walking/standing - picking up yard, light, picking flowers or vegetables
Lawn & Garden	08251	3.0	Walking, gathering gardening tools
Lawn & Garden	08255	4.8	Wheel barrow, pushing garden cart or wheelbarrow, general
Lawn & Garden	08256	6.0	Wheel barrow, pushing large garden cart or heavy wheelbarrow up to 150kg
Lawn & Garden	08260	2.3	Yardwork, general, light effort
Lawn & Garden	08261	4.0	Yardwork, general, moderate effort
Lawn & Garden	08262	6.0	Yardwork, general, vigorous effort
Miscellaneous	09000	1.3	Board game playing, sitting
Miscellaneous	09005	2.5	Casino gambling, standing
Miscellaneous	09010	1.5	Card playing, sitting
Miscellaneous	09013	1.5	Chess game, sitting
Miscellaneous	09015	1.5	Copying or filing documents, standing
Miscellaneous	09020	1.8	Drawing, writing, painting, standing
Miscellaneous	09025	1.0	Laughter, sitting
Miscellaneous	09030	1.0	Sitting: reading, book, newspaper, magazine
Miscellaneous	09034	1.8	sitting, typing or reading on a balance chair/stability ball
Miscellaneous	09036	2.0	watching tv, stepping during commercial breaks
Miscellaneous	09040	1.3	Sitting: writing, desk work, typing
Miscellaneous	09050	1.3	Standing: talking in person, on the phone, computer, text messaging, writing
Miscellaneous	09055	1.3	Sitting: talking in person, on the phone, computer, or text messaging, light effort
Miscellaneous	09060	1.5	Sitting - studying, general, including reading and/or writing, light effort
Miscellaneous	09065	1.8	Sitting - in class, general, including note-taking or class discussion
Miscellaneous	09070	1.0	Standing - reading
Miscellaneous	09071	2.5	Standing: miscellaneous
Miscellaneous	09075	1.8	Sitting: arts and crafts, carving wood, weaving, spinning wool, light effort
Miscellaneous	09080	3.0	Sitting: arts and crafts, carving wood, weaving, spinning wool, moderate effort
Miscellaneous	09085	2.5	Standing: arts and crafts, sand painting, carving, weaving, light effort
Miscellaneous	09090	3.3	Standing - arts and crafts, sand painting, carving, weaving, moderate effort
Miscellaneous	09095	3.5	Standing - arts and crafts, sand painting, carving, weaving, vigorous effort
Miscellaneous	09100	1.5	Retreat/family reunion activities involving sitting, relaxing, talking, eating
Miscellaneous	09101	2.5	Retreat/family reunion activities involving playing games with children
Miscellaneous	09105	2.0	Touring/traveling/vacation involving riding in vehicle
Miscellaneous	09106	3.5	Touring/traveling/vacation involving walking
Miscellaneous	09110	2.5	Camping involving standing, walking, sitting, light-to-moderate effort
Miscellaneous	09115	1.5	Sitting at a sporting event, spectator
Music Playing	10010	1.8	Accordion, sitting
Music Playing	10020	2.3	Cello, sitting
Music Playing	10030	2.3	Conducting orchestra, standing
Music Playing	10035	2.5	Double bass, standing

Occupation	11416	3.0	Lawn keeper, weeding, gas powered
Occupation	11418	3.3	Laundry worker
Occupation	11420	3.0	Locksmith
Occupation	11430	3.0	Machine tooling (e.g., machining, working sheet metal, machine fitter, operating lathe, welding) light-to-moderate effort
Occupation	11450	5.0	Machine tooling, operating punch press, moderate effort
Occupation	11472	1.8	Manager, property
Occupation	11475	2.8	Manual or unskilled labor, general, light effort
Occupation	11476	4.5	Manual or unskilled labor, general, moderate effort
Occupation	11477	6.5	Manual or unskilled labor, general, vigorous effort
Occupation	11480	4.3	Masonary, concrete, moderate effort
Occupation	11482	2.5	Masonry, concrete, light effort
Occupation	11485	5.5	Massage therapist, standing
Occupation	11486	2.3	Mail carrier, walking to deliver mail
Occupation	11487	1.5	Mail delivery, motorbike
Occupation	11488	3.5	Mail delivery, Electronically Assisted Bicycle
Occupation	11490	7.5	Moving, carrying or pushing heavy objects, 75 lbs or more, only active time (e.g., desks, moving van work)
Occupation	11493	8.5	Mining, general services, drilling, mining support jobs (mechanical, welding, pipe installation, general construction)
Occupation	11495	12.0	Skindiving or SCUBA diving as a frogman, Navy Seal
Occupation	11500	2.5	Operating heavy duty equipment, automated, not driving
Occupation	11510	3.5	Orange grove work, picking fruit
Occupation	11514	3.3	Painting, house, furniture, moderate effort
Occupation	11516	3.0	Plumbing activities
Occupation	11520	2.0	Printing, paper industry worker, standing
Occupation	11524	3.8	Police Officer, Walking
Occupation	11525	2.5	Police, directing traffic, standing
Occupation	11526	2.0	Police, driving a squad car, sitting
Occupation	11527	1.3	Police, riding in a squad car, sitting
Occupation	11528	4.0	Police, making an arrest, standing
Occupation	11529	9.0	Counter terrorism maneuvers, clearing building
Occupation	11530	2.0	Shoe repair, general
Occupation	11540	7.3	Shoveling, digging ditches
Occupation	11550	8.8	Shoveling, more than 16 lbs/minute, deep digging, vigorous effort
Occupation	11560	5.0	Shoveling, less than 10 lbs/minute, moderate effort
Occupation	11570	6.5	Shoveling, 10 to 15 lbs/minute, vigorous effort
Occupation	11580	1.5	Sitting tasks, light effort (e.g., office work, chemistry lab work, light assembly repair, watch repair, reading, desk work)
Occupation	11582	1.3	Sitting, computer work
Occupation	11583	1.3	Standing workstation, typing, computer work
Occupation	11585	1.3	Sitting meetings, light effort, general, and/or with talking involved (e.g., eating at a business meeting)
Occupation	11590	2.5	Sitting tasks, moderate effort (e.g. pushing heavy levers, riding mower/forklift, crane operation)
Occupation	11593	2.8	Sitting, teaching stretching or yoga, or light effort exercise classes
Occupation	11124	2.3	Construction, rebar, bar bending/fixing
Occupation	11125	2.3	Custodial work, light effort (e.g., cleaning sink and toilet, dusting, vacuuming, light cleaning)
Occupation	11126	3.8	Custodial work, moderate effort (e.g., buffing floors with electric buffer, feathering or sweeping arena floors, mopping, taking out the trash, vaccuming)
Occupation	11130	3.3	Electrical work (e.g., hook up wire, tapping splicing); plumbing moved to11516
Occupation	11135	1.8	Engineer (e.g., mechanical or electrical)
Occupation	11145	7.8	Farming, vigorous effort (e.g., baling hay, cleaning barn), includes former code 11200
Occupation	11146	4.8	Farming, moderate effort (e.g., feeding animals, chasing cattle by walking and/or horseback, spreading manure, harvesting crops)
Occupation	11147	2.0	Farming, light effort, (e.g., cleaning animal sheds, preparing animal feed)
Occupation	11170	2.8	Farming, driving tasks (e.g., driving tractor or harvester)
Occupation	11180	3.5	Farming, feeding small animals
Occupation	11190	4.3	Farming, feeding cattle, horses
Occupation	11191	4.3	Farming, hauling water for animals, fetching water from well or stream
Occupation	11192	4.5	Farming, taking care of animals (e.g., grooming, brushing, shearing sheep, assisting with birthing, medical care, branding), general
Occupation	11195	3.8	Farming, rice, planting, grain milling activities
Occupation	11210	3.5	Farming, milking by hand, cleaning pails, moderate effort
Occupation	11220	1.3	Farming, milking by machine, light effort
Occupation	11222	3.0	Farming, milking Cows, full milking process, modern milking parlor with milking machines
Occupation	11240	8.0	Fire fighter, general
Occupation	11244	6.8	Fire fighter, rescue victim, automobile accident, using pike pole
Occupation	11245	8.0	Fire fighter, raising and climbing ladder with full gear, simulated fire suppression
Occupation	11246	9.0	Fire fighter, hauling hoses on ground, carrying/hoisting equipment, breaking down walls etc., wearing full gear
Occupation	11247	3.5	Fishing, commercial, light effort
Occupation	11248	5.0	Fishing, commercial, moderate effort
Occupation	11250	17.5	Forestry, ax chopping, very fast, 1.25 kg axe, 51 blows/min, extremely vigorous effort
Occupation	11260	5.0	Forestry, ax chopping, slow, 1.25 kg axe, 19 blows/min, moderate effort
Occupation	11262	8.0	Forestry, ax chopping, fast, 1.25 kg axe, 35 blows/min, vigorous effort
Occupation	11264	5.0	Forestry, moderate effort (e.g., sawing wood with power saw, weeding, hoeing)
Occupation	11266	8.5	Forestry, vigorous effort (e.g., barking, felling, or trimming trees, carrying or stacking logs, planting seeds, sawing lumber by hand)
Occupation	11370	4.8	Furriery
Occupation	11375	3.8	Garbage collector, walking, dumping bins into truck, street cleaning
Occupation	11378	1.8	Hairstylist (e.g., plaiting hair, manicure, make up artist)
Occupation	11380	7.3	Horse grooming, including feeding, cleaning stalls, bathing, brushing, clipping, longeing and exercising horses.
Occupation	11381	4.3	Horse, feeding, watering, cleaning stalls, implied walking and lifting loads
Occupation	11383	4.5	Horseback riding, working, cutting cows
Occupation	11390	7.8	Horse racing, galloping, cantor
Occupation	11400	6.3	Horse racing, Jockey, trotting
Occupation	11410	2.3	Horse racing, Jockey, walking
Occupation	11413	3.0	Kitchen maid
Occupation	11415	4.0	Lawn keeper, yardwork, general

Occupation	11884	5.0	Airborne Shuffle, 2.5 to 3.5 mph, 20-30 kg load
Occupation	11886	6.3	Soldiers, military loaded marching, varying terrain, 25-40 kg load
Occupation	11887	6.0	Soldiers, walking, 2.8 mph, 5% grade, up to 21.5 kg load
Occupation	11888	8.5	Soldiers, walking, 2.8 mph, 10% grade, up to 21.5 kg load
Occupation	11889	11.0	Soldiers, walking, 2.8 mph, 15% grade, up to 21.5 kg load
Occupation	11892	6.0	Military activities, arterial field preparation, digging defensive positions
Running	12010	6.0	Jog/walk combination (jogging component of less than 10 minutes) (Taylor Code 180)
Running	12020	7.5	Jogging, general, self-selected pace
Running	12025	4.8	Jogging, in place
Running	12026	3.3	Jogging 2.6 to 3.7 mph
Running	12027	4.5	Jogging on a mini-tramp
Running	12028	6.5	Running, 4 to 4.2 mph (13 min/mile)
Running	12029	7.8	Running 4.3 to 4.8 mph
Running	12030	8.5	Running, 5.0 to 5.2 mph (12 min/mile)
Running	12045	9.0	Running, 5.5 -5.8 mph
Running	12050	9.3	Running, 6-6.3 mph (10 min/mile)
Running	12060	10.5	Running, 6.7 mph (9 min/mile)
Running	12070	11.0	Running, 7 mph (8.5 min/mile)
Running	12080	11.8	Running, 7.5 mph (8 min/mile)
Running	12090	12.0	Running, 8 mph (7.5 min/mile)
Running	12100	12.5	Running, 8.6 mph (7 min/mile)
Running	12110	13.0	Running, 9 mph (6.5 min/mile)
Running	12115	14.8	Running, 9.3 to 9.6 mph
Running	12120	14.8	Running, 10 mph (6 min/mile)
Running	12130	16.8	Running, 11 mph (5.5 min/mile)
Running	12132	18.5	Running, 12 mph (5.0 min/mile)
Running	12134	19.8	Running, 13 mph (4.6 min/mile)
Running	12135	23.0	Running, 14 mph (4.3 min/mile)
Running	12140	9.3	Running, cross country
Running	12145	10.5	Running, self-selected pace
Running	12150	8.0	Running (Taylor Code 200)
Running	12170	15.0	Running, stairs, up
Running	12180	10.0	Running, on a track, team practice
Running	12184	18.0	Running, on track, 500-1500m, competitive
Running	12186	19.3	Running, on track, 2000-3000m, competitive
Running	12190	8.0	Running, training, pushing a wheelchair or baby carrier
Running	12200	13.3	Running, marathon
Running	12255	10.3	Running uphill, 4.5mph, 5% incline
Running	12260	13.3	Running uphill, 6.0 mph, 5% incline
Running	12265	15.5	Running uphill, 7.0 mph, 5% incline
Running	12325	17.5	Running uphill, 5.0 to 5.9 mph, 15% incline
Running	12335	8.8	Running uphill, 0.6 to 0.79 mph, 30% incline
Running	12337	10.3	Running uphill, 0.8 to 0.99 mph, 30% incline
Occupation	11600	1.8	Standing tasks, light effort (e.g., bartending, store clerk, assembling, filing, duplicating, librarian, putting up a Christmas tree, standing and talking at work, changing clothes when teaching physical education)
Occupation	11610	3.3	Standing, light/moderate effort (e.g., assemble/repair heavy parts, welding, stocking parts, auto repair, packing boxes, nursing patient care, laundry)
Occupation	11615	4.5	Standing, moderate effort, lifting items continuously, 10 – 20 lbs, with limited walking or resting
Occupation	11620	3.8	Standing, moderate effort, intermittent lifting 50 lbs, hitch or twisting ropes
Occupation	11630	4.5	Standing, moderate/heavy tasks (e.g., lifting more than 50 lbs, masonry, painting, paper hanging)
Occupation	11650	2.3	Patient care, healthcare activites
Occupation	11660	3.5	Patient care, room cleaning/preperation
Occupation	11708	5.3	Steel mill, moderate effort (e.g., fettling, forging, tipping molds)
Occupation	11710	8.3	Steel mill, vigorous effort (e.g., hand rolling, merchant mill rolling, removing slag, tending furnace)
Occupation	11720	2.3	Tailoring, cutting fabric
Occupation	11730	2.5	Tailoring, general
Occupation	11740	1.8	Tailoring, hand sewing
Occupation	11750	2.5	Tailoring, machine sewing
Occupation	11760	3.5	Tailoring, pressing
Occupation	11763	2.0	Tailoring, weaving, light effort (e.g., finishing operations, washing, dyeing, inspecting cloth, counting yards, paperwork)
Occupation	11765	4.0	Tailoring, weaving, moderate effort (e.g., spinning and weaving operations, delivering boxes of yarn to spinners, loading of warp bean, pinwinding, conewinding, warping, cloth clutting)
Occupation	11766	6.5	Truck driving, loading and unloading truck, tying down load, standing, walking and carrying heavy loads
Occupation	11767	2.0	Truck driving, delivery truck, taxi, shuttlebus, school bus
Occupation	11770	1.3	Typing, electric, manual or computer
Occupation	11780	6.3	Using heavy power tools such as pneumatic tools (e.g., jackhammers, drills, etc.)
Occupation	11790	7.8	Using heavy tools (not power) such as shovel, pick, tunnel bar, spade
Occupation	11791	2.0	Walking on job, less than 2.0 mph, very slow speed, in office or lab area
Occupation	11792	3.8	Walking on job, 2.8 to 3.4 mph, in office, moderate speed, not carrying anything
Occupation	11793	4.8	Walking on job, 3.5 to 3.9 mph, in office, brisk speed, not carrying anything
Occupation	11795	3.5	Walking on job, 2.5 mph, slow speed, carrying light objects less than 25 lbs
Occupation	11796	3.0	Walking, gathering things at work, ready to leave
Occupation	11797	3.8	Walking, 2.5 mph, slow speed, carrying heavy objects more than 25 lbs
Occupation	11800	4.5	Walking, 3.0 mph, moderately and carrying light objects less than 25 lbs
Occupation	11805	3.8	Walking, pushing a wheelchair
Occupation	11810	4.5	Walking, 3.5 mph, briskly and carrying objects less than 25 lbs
Occupation	11820	4.0	Walking or walk downstairs or standing, carrying objects about 25 to 49 lbs
Occupation	11830	5.5	Walking or walk downstairs or standing, carrying objects about 50 to 74 lbs
Occupation	11840	7.0	Walking or walk downstairs or standing, carrying objects about 75 to 99 lbs
Occupation	11850	7.3	Walking or walk downstairs or standing, carrying objects about 100 lbs or more
Occupation	11860	2.3	Warehouse/Shipping Center, Loading/Unloading boxes
Occupation	11862	4.3	Warehouse/Shipping Center, Moving boxes (~5kg)
Occupation	11870	3.0	Working in scene shop, theater actor, backstage employee
Occupation	11880	3.5	Soldiers, military marching, unloaded 1.5-2.5 mph
Occupation	11882	4.0	Soldiers, military marching, 1.5-2.5 mph, 10 to 30 kg load

Sports	15000	5.5	Alaska Native Games, Eskimo Olympics, general
Sports	15010	4.3	Archery (non-hunting)
Sports	15020	7.0	Badminton, competitive (Taylor Code 450)
Sports	15025	9.0	Badminton, competitive, match play
Sports	15030	5.5	Badminton, social singles and doubles, general
Sports	15040	8.0	Basketball, game (Taylor Code 490)
Sports	15050	6.0	Basketball, non-game, general (Taylor Code 480)
Sports	15055	7.5	Basketball, general
Sports	15060	7.0	Basketball, officiating (Taylor Code 500)
Sports	15062	5.8	Basketball, officiating
Sports	15070	5.0	Basketball, shooting baskets
Sports	15072	9.3	Basketball, drills, practice
Sports	15080	2.5	Billiards
Sports	15090	3.0	Bowling (Taylor Code 390)
Sports	15092	3.8	Bowling, indoor, bowling alley
Sports	15100	12.3	Boxing, in ring, general
Sports	15110	5.8	Boxing, punching bag
Sports	15113	7.0	Boxing, punching bag, 60 b/min
Sports	15115	8.5	Boxing, punching bag, 120 b/min
Sports	15118	10.8	Boxing, punching bag, 180 b/min
Sports	15120	7.8	Boxing, sparring
Sports	15125	9.3	Boxing, simulated boxing round, exercise
Sports	15130	7.0	Broomball
Sports	15135	5.8	Children's games, adults playing (e.g., hopscotch, 4-square, dodge ball, playground apparatus, t-ball, tetherball, marbles, jacks, arcade games), moderate effort
Sports	15138	6.0	Cheerleading, gymnastic moves, competitive
Sports	15140	4.0	Coaching, football, soccer, basketball, baseball, swimming, etc.
Sports	15142	8.0	Coaching, actively playing sport with players
Sports	15150	4.8	Cricket, batting, bowling, fielding
Sports	15160	3.3	Croquet
Sports	15170	4.0	Curling
Sports	15180	2.5	Darts, wall or lawn
Sports	15190	6.0	Drag racing, pushing or driving a car
Sports	15192	8.5	Auto racing, open wheel
Sports	15195	7.8	Futsal
Sports	15200	6.0	Fencing, general
Sports	15203	9.8	Fencing, epee, competitive
Sports	15205	10.5	Floorball
Sports	15210	8.0	Football, competitive
Sports	15230	8.0	Football, touch, flag, general (Taylor Code 510)
Sports	15232	4.0	Football, touch, flag, light effort
Sports	15235	2.5	Football or baseball, playing catch
Sports	15240	3.0	Frisbee playing, general
Running	12339	11.8	Running uphill, 1.0 to 1.19 mph, 30% incline
Running	12341	13.5	Running uphill, 1.2 to 1.39 mph, 30-40% incline
Running	12343	14.8	Running uphill, 1.4 to 1.59 mph, 30% incline
Running	12345	16.3	Running uphill, >1.6mph, 10-30% incline
Running	12350	16.0	Running, hilly terrain, ±100m change in elevation
Running	12352	5.8	Running downhill, 5.0 to 5.9 mph, -10% to -15%
Running	12353	7.5	Running downhill, 6.0 to 6.9 mph, -10% to -15%
Running	12355	9.0	Running downhill, 7.0 to 8.9 mph, -10% to -15%
Running	12358	9.3	Running downhill, 6.0 to 7.9 mph, -3% to -9%
Running	12361	13.8	Running downhill, 8.0 to 10.5 mph, -3% to -9%
Running	12405	5.3	Running/jogging, curved treadmill, 3.0 to 3.9 mph
Running	12408	6.5	Running/jogging, curved treadmill, 4.0 to 4.9 mph
Running	12410	11.0	Running curved treadmill, 5.0 to 5.9 mph
Running	12412	12.0	Running curved treadmill, 7.0 to 7.9 mph
Running	12414	14.0	Running curved treadmill, 8.0 to 8.9 mph
Running	12416	16.8	Running curved treadmill, 9.0 to 9.9 mph
Running	12508	8.5	Running, 5.0 - 5.9 mph, 1.0 to 3.0 kg backpack
Running	12510	9.5	Running, 6.0 - 6.9 mph, 1.0 to 3.0 kg backpack
Running	12512	9.8	Running, 7.0 - 7.9 mph, 1.0 to 3.0 kg backpack
Running	12514	12.0	Running, 8.0 - 8.9 mph, 1.0 to 3.0 kg backpack
Running	12555	7.8	Running, barefoot, 3.5-5.9 mph
Running	12560	12.0	Running, barefoot, 6.0-7.9 mph
Running	12565	13.5	Running, barefoot, 8.0-8.9 mph
Running	12585	8.0	Running, jogging stroller, indoors, 5 mph
Running	12588	9.0	Running, jogging stroller, indoors, 6 mph
Running	12593	10.0	Running, jogging stroller, outdoors, 5 mph
Running	12595	11.5	Running, jogging stroller, outdoors, 6 mph
Running	12600	11.5	Skipping, 5.5-6.0 mph
Running	12620	13.0	Triathlon, Running
Self Care	13000	2.3	Getting ready for bed, general, standing
Self Care	13009	2.3	Sitting on toilet, eliminating while standing or squatting
Self Care	13010	1.5	Bathing, sitting
Self Care	13020	2.8	Dressing, undressing, standing or sitting
Self Care	13030	1.5	Eating, sitting
Self Care	13035	2.0	Talking and eating or eating only, standing
Self Care	13036	1.5	Taking medication, sitting or standing
Self Care	13040	2.0	Grooming, washing hands, shaving, brushing teeth, putting on make-up, sitting or standing
Self Care	13045	2.5	Hairstyling, standing
Self Care	13046	1.3	Having hair or nails done by someone else, sitting
Self Care	13050	2.0	Showering, toweling off, standing
Sexual Activity	14010	5.8	Active, vigorous effort
Sexual Activity	14020	3.0	General, moderate effort
Sexual Activity	14030	1.8	Passive, light effort, kissing, hugging

Sports	15477	7.0	Netball
Sports	15480	9.0	Orienteering
Sports	15490	10.0	Paddleball, competitive
Sports	15500	6.0	Paddleball, casual, general (Taylor Code 460)
Sports	15503	1.8	Paragliding, moderate altitude
Sports	15506	6.5	Prusik climbing
Sports	15510	8.0	Polo, on horseback
Sports	15520	10.0	Racquetball, competitive
Sports	15525	10.3	Race Walking, 3.1 m/s (6.9 mph)
Sports	15527	13.8	Race Walking, 3.7 m/s (8.3 mph)
Sports	15528	15.5	Race Walking, racing speed, 4.0 m/s (8.95 mph)
Sports	15530	7.0	Racquetball, general (Taylor Code 470)
Sports	15533	8.0	Rock or mountain climbing (Taylor Code 060), (formerly code 17120)
Sports	15534	8.8	Rock climbing, free boulder
Sports	15535	7.3	Rock climbing, ascending rock, high difficulty
Sports	15536	10.5	Rock climbing, speed climbing, very difficult
Sports	15537	5.8	Rock climbing, ascending or traversing rock, low-to-moderate difficulty
Sports	15538	10.5	Rock climbing, treadwall, 4-6 m/min
Sports	15539	10.5	Rock climbing, treadwall, 7-10 m/min
Sports	15540	5.0	Rock climbing, rappelling,
Sports	15542	4.0	Rodeo sports, general, light effort
Sports	15544	5.5	Rodeo sports, general, moderate effort
Sports	15546	7.0	Rodeo sports, general, vigorous effort
Sports	15550	12.3	Rope jumping, fast pace, 120-160 skips/min
Sports	15551	11.8	Rope jumping, moderate pace, general, 100 to 120 skips/min, 2 foot skip, plain bounce
Sports	15552	8.3	Rope jumping, slow pace, < 100 skips/min, 2 foot skip, rhythm bounce
Sports	15554	10.0	Rope jumping, double under or more
Sports	15560	8.3	Rugby, union, team, competitive
Sports	15562	6.3	Rugby, touch, non-competitive
Sports	15570	3.0	Shuffleboard
Sports	15580	5.0	Skateboarding, general, moderate effort
Sports	15582	6.0	Skateboarding, competitive, vigorous effort
Sports	15590	7.0	*Skating, roller (Taylor Code 360)*
Sports	15591	7.5	Roller blading, in-line skating, 14.4 km/h (9.0 mph), recreational pace
Sports	15592	9.8	Roller blading, in-line skating, 17.7 km/h (11.0 mph), moderate pace, exercise training
Sports	15593	12.3	Roller blading, in-line skating, 21.0 to 21.7 km/h (13.0 to 13.6 mph), fast pace, exercise training
Sports	15594	15.5	Rollerblading, in-line skating, 24.0 km/h (15.0 mph), maximal effort
Sports	15595	6.8	Skateboard, longboard, 13.3 km/h, slow speed
Sports	15596	8.3	Skateboard, longboard, 16.2 km/h, typical speed
Sports	15597	10.5	Skateboard, longboard, 13.3 km/h, fast speed
Sports	15600	3.5	Skydiving, base-jumping, bungee jumping
Sports	15605	9.5	Soccer, competitive
Sports	15610	7.0	Soccer, casual, general (Taylor Code 540)
Sports	15250	8.0	Frisbee, ultimate
Sports	15252	3.8	Frisbee golf
Sports	15255	4.5	Golf, general
Sports	15265	4.3	Golf, walking, carrying clubs
Sports	15270	3.5	Golf, miniature, driving range
Sports	15285	4.5	Golf, walking, pulling clubs
Sports	15290	3.5	Golf, using power cart (Taylor Code 070)
Sports	15300	3.8	Gymnastics, general
Sports	15310	4.0	Hacky sack
Sports	15320	12.0	Handball, general (Taylor Code 520)
Sports	15330	8.0	Handball, team
Sports	15335	4.0	High ropes course, multiple elements
Sports	15340	3.5	Hang gliding
Sports	15350	7.8	Hockey, field
Sports	15360	8.0	Hockey, ice, general
Sports	15362	10.0	Hockey, ice, competitive
Sports	15370	5.5	*Horseback riding, general*
Sports	15380	4.5	Horse grooming, maintenance, saddling tasks
Sports	15390	5.8	Horseback riding, trotting
Sports	15395	7.3	Horseback riding, canter or gallop
Sports	15400	3.8	Horseback riding, walking
Sports	15402	9.0	Horseback riding, jumping
Sports	15403	6.0	Horseback riding, reining
Sports	15406	2.1	Horseback riding, simulator
Sports	15408	1.8	Horse cart, driving, standing or sitting
Sports	15410	3.0	Horseshoe pitching, quoits
Sports	15420	12.0	Jai alai
Sports	15425	5.3	Martial Arts, different types, slower pace, novice performers, practice
Sports	15430	10.3	Martial Arts, different types, moderate pace (e.g., judo, jujitsu, karate, kick boxing, tae kwon do, tai-bo, Muay Thai boxing)
Sports	15432	14.3	Taekwondo, combat simulation
Sports	15433	11.3	Judo
Sports	15440	4.0	Juggling
Sports	15444	6.5	Kendu, kihon-keiko style, moderate intensity
Sports	15445	9.6	Kendu, kirikaeshi style, high intensity
Sports	15446	11.3	Kendu, kakari keiko style, very high intensity
Sports	15450	7.0	Kickball
Sports	15455	5.5	Kung Fu Gymnastics
Sports	15457	7.3	Kickboxing
Sports	15460	8.0	Lacrosse
Sports	15465	3.3	Lawn bowling, bocce ball, outdoor
Sports	15470	4.0	Motocross, off-road motor sports, all-terrain vehicle, general
Sports	15475	5.3	Motorcycle racing, Supermoto racing

Walking	17012	7.8	Backpacking, hiking with a daypack, organized walking with daypack
Walking	17016	4.0	Carrying 5 to 14 lb (2.3 to 6.4 kg) load (e.g. suitcase, boxes, groceries), level ground, moderate pace
Walking	17018	4.5	Carrying 15 - 155 lb (6.8 - 70.4 kg) load (e.g. suitcase, boxes, furniture), level ground or downstairs, slow pace
Walking	17019	6.5	Carrying 50 to 150 pound load (e.g., equine or bovine feed, fence pipes, furniture), level ground, moderate pace
Walking	17021	2.3	Carrying ~10 lb child, slow walking
Walking	17025	8.3	Carrying load upstairs, general
Walking	17026	5.5	Carrying load, 1 to 15 lb load, upstairs
Walking	17027	6.0	Carrying load, 16 to 24 lb load, upstairs
Walking	17028	8.0	Carrying load, 25 to 49 lb load, upstairs
Walking	17029	10.0	Carrying load, 50 to 74 lb load, upstairs
Walking	17030	12.0	Carrying load, >74 lb load, upstairs
Walking	17031	3.8	Loading and/or unloading a car, implied walking
Walking	17032	5.0	Climbing hills, no load, 5 to 20% grade, very slow pace
Walking	17033	3.8	Climbing hills, 15-50 lb load, 1 to 2% grade, slow pace
Walking	17034	5.3	Climbing hills, no load, 1 to 5% grade, moderate-to-brisk pace
Walking	17035	7.0	Climbing hills, no load, 6 to 10% grade, moderate-to-brisk pace
Walking	17036	8.8	Climbing hills, no load, 11 to 20% grade, slow-to-moderate pace
Walking	17037	10.0	Climbing hills, no load, 4.0 to 5.0 mph, 3 to 5% grade, very fast pace
Walking	17038	8.5	Climbing hills, no load, steep grade (30%), slow pace (less than 1.2 mph)
Walking	17039	15.5	Climbing hills, no load, very steep grade (30-40%), 1.2 to 1.8 mph
Walking	17040	16.3	Climbing hills, no load, steep grade (10-40%), 1.8 to 5.0 mph
Walking	17045	6.5	Climbing hills, 10 to 20 lb load, 5 to 10% grade, moderate
Walking	17050	7.5	Climbing hills, 21 to 40 lb load, 3 to 10% grade, moderate-to-brisk pace
Walking	17060	10.0	Climbing hills, 20+ pound load, 5 to 20% grade, moderate to brisk pace
Walking	17070	3.5	Descending stairs
Walking	17076	4.5	Hauling water, head hauling, walking on flat surface
Walking	17080	6.0	Hiking, cross country (Taylor Code 040)
Walking	17081	3.8	Hiking slowly or ambling through fields and hillsides, no load
Walking	17082	5.3	Hiking or walking at a normal pace through fields and hillsides, no load
Walking	17085	2.5	Bird watching, walking and stopping
Walking	17088	4.5	Marching, moderate speed, military, no pack
Walking	17090	8.0	Marching rapidly, military, no pack
Walking	17100	3.8	Pushing or pulling stroller with child or walking with children, 2.5 to 3.1 mph
Walking	17105	3.8	Pushing a wheelchair, non-occupational
Walking	17110	6.5	Race walking
Walking	17130	8.0	Stair climbing, using or climbing up ladder (Taylor Code 030)
Walking	17131	6.8	Stair climbing, general
Walking	17133	4.5	Stair climbing, slow pace
Walking	17134	9.3	Stair climbing, fast pace, one step at a time
Walking	17136	7.5	Stair climbing, two steps at a time
Walking	17138	7.5	Stair climbing, ascending and descending stairs
Walking	17140	4.5	Using crutches, level ground, general
Walking	17142	7.0	Using crutches, fast pace
Sports	15615	3.5	Walking football/soccer
Sports	15620	5.0	Softball or baseball, fast or slow pitch, general, moderate effort (Taylor Code 440)
Sports	15625	4.0	Softball, practice
Sports	15630	4.0	Softball, officiating
Sports	15640	6.0	Softball, pitching
Sports	15645	3.3	Sports spectator, very excited, emotional, physically moving
Sports	15650	12.0	Squash (Taylor Code 530)
Sports	15652	7.3	Squash, general
Sports	15660	4.0	Table tennis, ping pong (Taylor Code 410)
Sports	15670	3.3	Tai chi, qi gong, general
Sports	15672	1.5	Tai chi, qi gong, sitting, light effort
Sports	15674	6.0	Tai chi chuan, Yang style
Sports	15675	6.8	Tennis, general, moderate effort
Sports	15676	8.0	Tennis, general, competitive
Sports	15680	6.0	Tennis, doubles (Taylor Code 430)
Sports	15685	4.5	Tennis, doubles
Sports	15690	8.0	Tennis, singles (Taylor Code 420)
Sports	15695	5.0	Tennis, hitting balls, non-game play, moderate effort
Sports	15700	6.3	Trampoline, recreational
Sports	15702	10.3	Trampoline, competitive
Sports	15710	4.0	Volleyball (Taylor Code 400)
Sports	15711	6.0	Volleyball, competitive, in gymnasium
Sports	15720	3.0	Volleyball, non-competitive, 6 - 9 member team, general
Sports	15725	8.0	Volleyball, beach, in sand
Sports	15730	6.0	Wrestling, competitive (one match = 5 minutes)
Sports	15731	7.0	Wallyball, general
Sports	15732	4.0	Track and field (e.g., shot, discus, hammer throw)
Sports	15733	6.0	Track and field (e.g., high jump, long jump, triple jump, javelin, pole vault)
Sports	15734	10.0	Track and field (e.g., steeplechase, hurdles)
Transportation	16002	9.3	Bicycling for transportation, light effort
Transportation	16004	9.3	Bicycling for transportation, high effort
Transportation	16005	6.8	E-bike (electrically assisted) for transportation
Transportation	16010	2.0	Automobile or light truck (not a semi) driving
Transportation	16015	1.3	Riding in a car or truck
Transportation	16016	1.3	Riding in a bus or train
Transportation	16020	1.8	Flying airplane or helicoptor
Transportation	16030	2.8	Motor scooter, motorcycle
Transportation	16035	6.3	Pulling rickshaw
Transportation	16040	6.0	Pushing plane in and out of hangar
Transportation	16050	2.5	Truck, semi, tractor, ≥1 ton, or bus, driving
Transportation	16060	3.5	Walking for transportation, 2.8-3.2 mph, level, moderate pace, firm surface
Walking	17010	7.0	Backpacking (Taylor Code 050)
Walking	17011	3.5	Walking with a day pack, level ground, assumed in the city

Walking	17434	4.8	Walking, treadmill, 2.5 mph, 0% grade, 5 to 20 degrees C, 40 lb (18.2 kg) load
Walking	17438	5.8	Walking, treadmill, 2.5 mph, 0% grade, -10 to 0 degrees C, 40 lb (18.2 kg) load
Walking	17455	8.3	Walking, Curved treadmill, 3.0 to 5.0 mph, brisk pace
Walking	17475	7.8	Walking treadmill, backwards, 2.5 mph, +10% grade
Walking	17492	1.5	Walking, with a walker or step-to gait on treadmill, 0.7 mph (1.1 km/h), 0% grade
Water Activities	18010	2.5	Boating, power, driving
Water Activities	18012	1.3	Boating, power, passenger, light
Water Activities	18020	4.0	Canoeing, on camping trip (Taylor Code 270)
Water Activities	18025	3.3	Canoeing, harvesting wild rice, knocking rice off the stalks
Water Activities	18030	7.0	Canoeing, portaging
Water Activities	18040	2.8	Canoeing, rowing, 2.0-3.9 mph, light effort
Water Activities	18050	5.8	Canoeing, rowing, 4.0-5.9 mph, moderate effort
Water Activities	18060	12.5	Canoeing, rowing, kayaking, competition, > 6 mph, vigorous effort
Water Activities	18070	3.5	Canoeing, rowing, for pleasure, general (Taylor Code 250)
Water Activities	18080	12.0	Canoeing or rowing, in competition, crew or sculling (Taylor Code 260)
Water Activities	18090	3.0	Diving, springboard or platform
Water Activities	18100	5.0	Kayaking, moderate effort
Water Activities	18104	13.5	Kayaking, competition
Water Activities	18106	9.0	Kayaking, slalom, flat water
Water Activities	18110	4.0	Paddle boat
Water Activities	18112	15.5	Rowing, simulated crew in a water tank, single oar, 33 strokes/min,
Water Activities	18114	15.5	Rowing, single scull, ergometer, ergometer on slides, racing speed (32+ strokes/min, >10 mph)
Water Activities	18120	3.0	Sailing, boat and board sailing, windsurfing, ice sailing, general (Taylor Code 235)
Water Activities	18130	4.5	Sailing, in competition, general
Water Activities	18132	9.3	Sailing, in competition, high effort
Water Activities	18140	3.3	Sailing, Sunfish/Laser/Hobby Cat, Keel boats, ocean sailing, yachting, leisure
Water Activities	18142	2.0	Sailing, dingy
Water Activities	18150	6.0	Skiing, water or wake boarding (Taylor Code 220)
Water Activities	18160	7.0	Jet skiing, driving, in water
Water Activities	18180	15.8	Skindiving, fast
Water Activities	18190	11.8	Skindiving, moderate
Water Activities	18200	7.0	Skindiving, scuba diving, general (Taylor Code 310)
Water Activities	18202	5.3	Scuba diving, general, light effort
Water Activities	18204	5.8	Scuba diving, general, moderate effort
Water Activities	18206	5.5	Scuba diving, professional diver
Water Activities	18208	6.8	Scuba diving, recreational diver
Water Activities	18210	5.0	Snorkeling (Taylor Code 320)
Water Activities	18220	3.0	Surfing, body or board, general
Water Activities	18221	6.8	Surfboard, paddling
Water Activities	18222	5.0	Surfing, body or board, competitive
Water Activities	18224	6.5	Stand up paddle boarding, general
Water Activities	18225	2.8	Stand up Paddleboard, standing, 10-19 strokes/min
Water Activities	18226	3.8	Stand up Paddleboard, standing, 20-29 strokes/min
Walking	17145	4.3	Using medical knee scooter
Walking	17150	2.3	Walking, household
Walking	17151	2.3	Walking, less than 2.0 mph, level, strolling, very slow
Walking	17152	2.8	Walking, 2.0 to 2.4 mph, level, slow pace, firm surface
Walking	17160	3.5	Walking for pleasure (Taylor Code 010)
Walking	17161	2.5	Walking from house to car or bus, from car or bus to go places, from car or bus to and from the worksite
Walking	17162	2.5	Walking to neighbor's house or family's house for social reasons
Walking	17165	3.0	Walking the dog
Walking	17170	3.0	Walking, 2.5 mph, firm, level surface
Walking	17180	3.3	Walking, 2.5 mph, downhill
Walking	17190	3.8	Walking, 2.8 to 3.4 mph, level, moderate pace, firm surface
Walking	17200	4.8	Walking, 3.5 to 3.9 mph, level, brisk, firm surface, walking for exercise
Walking	17220	5.5	Walking, 4.0 to 4.4 mph (6.4 to 7.0 km/h), level, firm surface, very brisk pace
Walking	17230	7.0	Walking, 4.5 to 4.9 mph, level, firm surface, very, very brisk
Walking	17231	8.5	Walking, 5.0 to 5.5 mph (8.8 to 8.9 km/h), level, firm surface
Walking	17250	3.5	Walking, for pleasure, work break (Taylor Code xxx)
Walking	17255	4.0	Walking, self-selected speed, indoor track or outdoors, firm surface
Walking	17260	4.8	Walking, grass track
Walking	17262	4.5	Walking, normal pace, plowed field or sand
Walking	17270	4.0	Walking, to work or class (Taylor Code 015)
Walking	17280	2.5	Walking, to and from an outhouse
Walking	17302	4.3	Walking, for exercise, 2.5 to 3.5 mph (4.0 to 5.6 km/h), with ski poles, Nordic walking, level, moderate pace
Walking	17304	5.3	Walking, for exercise, 3.6 to 4.4 mph (5.8 to 7.1 km/h), with ski poles, Nordic walking, level, moderate pace
Walking	17305	8.5	Walking, for exercise, 4.5 to 5.0 mph, with ski poles, Nordic walking, level, fast pace
Walking	17310	8.8	Walking, for exercise, with ski poles, Nordic walking, uphill, moderate pace
Walking	17313	10.8	Walking, for exercise, with ski poles, Nordic walking, level ground, carrying 20 to 30 lb load (9.0 to 15.0 kg)
Walking	17315	12.3	Walking, for exercise, with ski poles, Nordic walking, uphill, carrying 20 to 30 lb load (9.0 to 15.0 kg)
Walking	17320	6.0	Walking, backward, 3.5 mph, level
Walking	17325	7.8	Walking, backward, 3.5 mph, uphill, 5% grade
Walking	17330	8.0	Walking, Teabag walk, Monty Python Ministry of Silly Walks
Walking	17332	3.5	Walking, Putey walk, Monty Python Ministry of Silly Walks
Walking	17340	2.1	Walking, treadmill, less than 1.0 mph, 0% grade
Walking	17343	2.3	Walking, treadmill, 1.0 mph, 0% grade
Walking	17346	2.8	Walking, treadmill, 1.2 to 1.9 mph, 0% grade (1.9 to 3.0 km/h)
Walking	17349	3.0	Walking, treadmill, 2.0 to 2.4 mph (3.2 to 3.9 km/h), 0% grade
Walking	17352	3.5	Walking, treadmill, 2.5 to 2.9 mph (4.0 to 4.7 km/h), 0% grade
Walking	17355	3.8	Walking, treadmill, 3.0 to 3.4 mph (4.8 to 5.5 km/h), 0% grade
Walking	17358	4.8	Walking, treadmill, 3.5 to 3.9 mph (5.6 to 6.3 km/h), 0% grade
Walking	17361	5.8	Walking, treadmill, 4.0 to 4.4 mph (6.4 to 7.1 km/h), 0% grade
Walking	17364	6.8	Walking, treadmill, 4.5 to 4.9 mph (7.2 to 7.9 km/h), 0% grade
Walking	17367	8.3	Walking, treadmill, 5.0 to 5.5 mph (8.0 to 8.9 km/h), 0% grade
Walking	17382	3.3	Walking, treadmill, downhill (-3% to -12% grade), 2.8 to 3.1 mph
Walking	17412	3.3	Walking, treadmill, downhill (-5% to -25% grade), 2.8 mph, with Nordic Poles

Water Activities	18420	5.0	Aquatic cycling, 75 W, 40-50 RPM
Water Activities	18424	6.3	Aquatic cycling, 75 W, 60-70 RPM
Water Activities	18428	6.3	Aquatic cycling, 100 W, 40-50 RPM
Water Activities	18432	7.5	Aquatic cycling, 100 W, 60-70 RPM
Water Activities	18436	8.5	Aquatic cycling, 80-89 RPM
Water Activities	18440	10.3	Aquatic cycling, 90+ RPM
Winter Activities	19005	7.5	Dog sledding, mushing
Winter Activities	19006	2.5	Dog sledding, passenger
Winter Activities	19010	6.0	Moving icehouse, set up/drill holes
Winter Activities	19011	2.0	Ice fishing
Winter Activities	19018	14.0	Skating, ice dancing
Winter Activities	19020	5.5	Skating, ice, 9 mph or less
Winter Activities	19030	7.0	Skating, ice, general (Taylor Code 360)
Winter Activities	19040	9.0	Skating, ice, rapidly, more than 9 mph but not competitive
Winter Activities	19045	9.0	Skating Treadmill, 6 - 6.9 mph, 2% grade
Winter Activities	19046	10.0	Skating Treadmill, 7 - 7.9 mph, 2% grade
Winter Activities	19047	10.5	Skating Treadmill, 8 - 8.9 mph, 2% grade
Winter Activities	19048	11.0	Skating Treadmill, 9 - 9.9 mph, 2% grade
Winter Activities	19050	13.8	Skating, speed, competitive
Winter Activities	19060	7.0	Ski jumping, climb up carrying skis
Winter Activities	19075	7.0	Skiing, general
Winter Activities	19080	6.8	Skiing, cross country, 2.5 mph, slow or light effort, ski walking
Winter Activities	19090	8.5	Skiing, cross country, 4.0-4.9 mph, moderate speed and effort, general
Winter Activities	19100	11.3	Skiing, cross country, 5.0-7.9 mph, brisk speed, vigorous effort
Winter Activities	19110	14.0	Skiing, cross country, elite skier, >8.0-11.9 mph, racing
Winter Activities	19112	16.0	Skiing, cross country, 12-16 mph, elite skier, racing
Winter Activities	19115	9.5	Skiing, cross-country skiing high-intensity training
Winter Activities	19130	15.5	Skiing, cross country, hard snow, uphill, maximum, snow mountaineering
Winter Activities	19135	13.3	Skiing, cross-country, skating
Winter Activities	19140	13.5	Skiing, cross-country, biathlon, skating technique
Winter Activities	19142	12.8	Biathlon training, 5 degree incline, 8 km/h (5 mph), with/without rifle
Winter Activities	19144	12.8	Biathlon training, 5 degree incline, 10.7 km/h (5 mph), with/without rifle
Winter Activities	19146	9.3	Skiing, slalom
Winter Activities	19150	4.3	Skiing, downhill, alpine or snowboarding, light effort, active time only
Winter Activities	19160	6.3	Skiing, downhill, alpine or snowboarding, moderate effort, general, active time only
Winter Activities	19170	8.0	Skiing, downhill, alpine or snowboarding, vigorous effort, active time only
Winter Activities	19174	7.3	Skiing, Alpine skiing high-intensity training
Winter Activities	19180	7.0	Sledding, tobogganing, bobsledding, luge (Taylor Code 370)
Winter Activities	19190	5.3	Snow shoeing, moderate effort
Winter Activities	19192	10.0	Snow shoeing, vigorous effort
Winter Activities	19200	3.8	Snowmobiling, driving, moderate pace, flat land
Winter Activities	19201	7.5	Snowboarding, recreational, moderate pace, mountain
Winter Activities	19202	2.0	Snowmobiling, passenger, light
Water Activities	18227	5.0	Stand up Paddleboard, standing, 30-39 strokes/min
Water Activities	18228	9.8	Stand up Paddleboard, standing, 40-49 strokes/min
Water Activities	18229	11.0	Stand up Paddleboard, standing, 50-69 strokes/min
Water Activities	18230	9.8	Swimming laps, freestyle, fast, vigorous effort
Water Activities	18240	5.8	Swimming laps, freestyle, slow, recreational
Water Activities	18250	9.5	Swimming, backstroke, training or competition
Water Activities	18255	4.8	Swimming, backstroke, recreational
Water Activities	18260	10.3	Swimming, breaststroke, general, training or competition
Water Activities	18265	5.3	Swimming breaststroke, recreational
Water Activities	18270	13.8	Swimming, butterfly, general
Water Activities	18280	10.5	Swimming, crawl, fast speed, ~75 yards/minute, vigorous effort
Water Activities	18285	10.5	Swimming, open water, 5k
Water Activities	18290	8.00	Swimming, crawl, medium speed, ~50 yards/minute, vigorous effort
Water Activities	18292	5.8	Swimming, crawl, slow speed, 30-45 yards/minute, moderate effort
Water Activities	18294	14.5	Swimming, crawl, elite swimmers, competition, >90 yards/minute
Water Activities	18300	6.0	Swimming, lake, ocean, river (Taylor Codes 280, 295)
Water Activities	18310	6.0	Swimming, leisurely, not lap swimming, general
Water Activities	18320	7.0	Swimming, sidestroke, general
Water Activities	18330	8.0	Swimming, synchronized
Water Activities	18340	9.8	Swimming, treading water, fast, vigorous effort
Water Activities	18350	3.5	Swimming, treading water, moderate effort, general
Water Activities	18352	2.3	Tubing, floating on a river, general
Water Activities	18355	5.5	Water aerobics, water calisthenics, general
Water Activities	18356	3.8	Water aerobics, resistance exercises
Water Activities	18358	7.5	Water aerobics, high intensity
Water Activities	18360	10.0	Water polo
Water Activities	18365	3.0	Water volleyball
Water Activities	18366	9.8	Water jogging, vigorous effort
Water Activities	18367	2.5	Water walking, light effort, slow pace
Water Activities	18368	4.8	Water walking, moderate effort, moderate pace
Water Activities	18369	6.8	Water walking, vigorous effort, brisk pace
Water Activities	18370	5.0	Whitewater rafting, kayaking, or canoeing
Water Activities	18374	6.5	Water running, 30 steps/min, slow
Water Activities	18375	7.5	Water running, 40 steps/min, moderate
Water Activities	18376	8.5	Water running, 50 steps/min, fast
Water Activities	18377	9.8	Water running, 60 steps/min, very fast
Water Activities	18380	5.0	Windsurfing, not pumping for speed
Water Activities	18385	11.0	Windsurfing or kitesurfing, crossing trial
Water Activities	18390	14.0	Windsurfing, competition, pumping for speed
Water Activities	18404	2.8	Aquatic cycling, 25 W, 40-50 RPM
Water Activities	18408	4.8	Aquatic cycling, 25 W, 60-70 RPM
Water Activities	18412	3.8	Aquatic cycling, 50 W, 40-50 RPM
Water Activities	18416	6.0	Aquatic cycling, 50 W, 60-70 RPM

Winter Activities	19252	5.3	Snow shoveling, by hand, moderate effort
Winter Activities	19254	7.5	Snow shoveling, by hand, vigorous effort
Winter Activities	19260	2.5	Snow blower, walking and pushing
Winter Activities	19300	12.5	Skiing, roller, elite racers
Winter Activities	19305	5.5	Rollerskiing, 10 - 12.9 km/h, no incline
Winter Activities	19310	6.8	Rollerskiing, 13 - 16.9 km/h, no incline
Winter Activities	19315	8.3	Rollerskiing, 17 - 19.9 km/h, no incline
Winter Activities	19320	10.5	Rollerskiing, 20 - 23.9 km/h, no incline
Winter Activities	19325	15.0	Rollerskiing, 24 - 27.9 km/h, no incline
Winter Activities	19330	12.5	Rollerskiing, 10-15 km/h, 2-5 degree incline
Winter Activities	19335	14.3	Rollerskiing, 16-22 km/h, 2-5 degree incline
Winter Activities	19340	12.3	Rollerskiing, 6-9 km/h, 6-10 degree incline
Winter Activities	19345	16.0	Rollerskiing, >10 km/h, 6-10 degree incline
Winter Activities	19400	9.0	Mountaineering, downhill climbing, walking down with rope
Winter Activities	19405	10.3	Mountaineering, downhill climbing/cross-country skiing
Religious Activities	20000	1.0	Sitting in church, in service, attending a ceremony, sitting quietly
Religious Activities	20001	2.0	Sitting, playing an instrument at church
Religious Activities	20005	1.8	Sitting in church, talking or singing, attending a ceremony, sitting, active participation
Religious Activities	20010	1.5	Sitting, reading religious materials at home
Religious Activities	20015	1.3	Standing quietly in church, attending a ceremony
Religious Activities	20020	2.0	Standing, singing in church, attending a ceremony, standing, active participation
Religious Activities	20025	1.3	Kneeling in church or at home, praying
Religious Activities	20030	1.3	Standing, talking in church
Religious Activities	20035	2.0	Walking in church
Religious Activities	20036	2.0	Walking, less than 2.0 mph, very slow
Religious Activities	20037	3.8	Walking, 2.8 to 3.4 mph, moderate speed, not carrying anything
Religious Activities	20038	4.8	Walking, 3.5 to 3.9 mph, brisk speed, not carrying anything
Religious Activities	20039	2.0	Walk/stand combination for religious purposes, usher
Religious Activities	20040	5.0	Praise with dance or run, spiritual dancing in church
Religious Activities	20045	2.3	Serving food at church
Religious Activities	20046	2.0	Preparing food at church
Religious Activities	20047	3.3	Washing dishes, cleaning kitchen at church
Religious Activities	20050	1.5	Eating at church
Religious Activities	20055	2.0	Eating/talking at church or standing eating, American Indian Feast days
Religious Activities	20060	3.3	Cleaning church
Religious Activities	20061	4.0	General yard work at church
Religious Activities	20065	3.8	Standing , moderate effort (e.g., lifting heavy objects, assembling at fast rate)
Religious Activities	20095	4.5	Standing, moderate-to-heavy effort, manual labor, lifting ≥ 50 lbs, heavy maintenance
Religious Activities	20100	1.3	Typing, electric, manual, or computer
Volunteer Activities	21000	1.3	Sitting, meeting, general, and/or with talking involved
Volunteer Activities	21005	1.5	Sitting, light office work, in general
Volunteer Activities	21010	2.5	Sitting, moderate work
Volunteer Activities	21015	1.8	Standing, light work (filing, talking, assembling)

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