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The Need For Speed: Evaluating the Speed of Carbohydrate Supplement Absorption in an Athletic Population

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(BSc Hons)

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ABSTRACT

Carbohydrate supplementation is a strategy used by athletes to enhance performance and delay fatigue during endurance or high-intensity exercise. Carbohydrates are a primary fuel source for muscles, especially during prolonged or intense physical activity, where glycogen can be depleted. Supplementing with easily digestible carbohydrate sources, like bars or gels, helps maintain blood glucose, replenish glycogen stores, and enhance performance. While the effectiveness of carbohydrate supplementation is well documented, the variety of commercially available products, each with differing carbohydrate compositions, warrants further exploration of their specific metabolic effects and practical benefits. This thesis investigates the ecological validity of three popular commercially available carbohydrate energy supplements, focusing on their ability to provide rapid energy and how this may influence performance outcomes. The first study assessed the speed of carbohydrate delivery from a glucose-fructose energy bar (Voom Pocket Rocket, VOOM), a glucose-fructose hydrogel (Maurten Gel 160, MAU), and a maltodextrin-based gel (SIS Go Isotonic, SIS). A modified oral glucose tolerance test revealed VOOM provided carbohydrates as quickly, if not faster, than MAU and SIS, with significantly greater carbohydrate oxidation than SIS. The second study examined the effects of these products on repeated maximal sprint performance. Despite differences in metabolic responses over time, no significant effects were found on sprint performance metrics, like peak power or total work. Collectively, the findings of this thesis highlight that while carbohydrate delivery speed may vary between products, the type of supplement may not significantly affect sprint performance. This thesis directly compares commercially available energy supplements - a glucose-fructose energy bar, a glucose-fructose hydrogel, and a maltodextrin-based gel - each with distinct carbohydrate compositions. These findings provide valuable insights to help athletes make informed decisions about carbohydrate supplementation, allowing them to choose based on personal preference and convenience, with confidence that these products offer comparable performance benefits.

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Declaration

Data Statement

All the data presented within this thesis were collected, analysed and presented by me unless otherwise stated below.

Ash Osborne, a laboratory technician at Lancaster University Medical School, inserted venous cannulas and helped to withdraw blood from participants for analysis.

I declare that all of the data presented is my own work unless stated otherwise and
this thesis was constructed by me. Appropriate referencing has been used for all the published literature referred to within this thesis. None of the data presented within this thesis has previously been submitted for assessment towards a higher degree.

Ewan Dean
March 2025

Conflict of interest statement

This research was funded by Omega Pharma Ltd, trading as Team Nutrition. The funder had no role in the design of this study and will not have any role during its execution, analyses, interpretation of the data, or decision to submit results.

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1. CHAPTER 1: General introduction

In recent years, the field of sports nutrition has experienced significant growth, driven by an increasing recognition of the vital role nutrition plays in enhancing athletic performance and supporting general health. As athletes and active individuals aim to optimise their physical performance, nutritional strategies and nutritional ergogenic aids have become key tools for achieving a wide range of performance-related goals, such as muscle growth, recovery, enhanced endurance, and cognitive function (Kerksick et al., 2018). According to Grand View Research (2023), the global sports nutrition market was valued at $45.24 billion in 2023, with projections indicating this may reach $75 billion by 2030. This reflects the growing demand for nutritional interventions aimed at improving both performance and well-being.

However, the rapid expansion of the sports nutrition industry also raises concerns regarding the efficacy and regulation of many commercially available products, as research has not always kept pace with product development (Kerksick et al., 2018). Nutritional supplements, such as creatine, whey protein, vitamins, energy bars, gels, and drinks, are commonly used by athletes to support specific physiological needs, yet their effectiveness varies widely depending on factors such as formulation, dosage, and individual response (Kerksick et al., 2018; Bucci 2020).

Furthermore, the safety of commercial nutritional supplements, both in terms of health and potential for accidental doping, remains a largely overlooked issue among consumers. Research by Duiven et al., (2021) from the Netherlands found that 25 of the 66 (38%) commercially available sports nutrition products tested contained undeclared doping substances. This highlights that sports nutrition supplements can contain undeclared doping substances, posing both risks to health and unintentional doping violations in elite sports. However, certifications such as Informed Sport testing ensure that products have been independently tested for banned substances, providing athletes with a safe option (Informed Sport, 2025). Consumers, both elite athletes and recreationally active individuals,

should be made aware of the science behind the supplements they consume to make informed decisions about their effectiveness and potential risks.

1.1 Why is sports nutrition so important?

A key factor influencing exercise performance is the body's ability to generate adenosine triphosphate (ATP), the primary energy source for cells (González-Marenco et al., 2024), a process heavily influenced by an individual's nutritional intake. Muscle contractions, essential for movement, rely on the availability of ATP, which is generated through a series of metabolic processes, with carbohydrates serving as the most significant fuel for ATP production during high-intensity and endurance activities (Hargreaves & Spriet, 2020). The breakdown of glucose into ATP during exercise occurs through a series of biochemical events.

The process of glucose breakdown and ATP production starts with glycolysis, which occurs in the cytoplasm of cells. Glycolysis breaks down glucose into two pyruvate molecules, producing a small volume of ATP in the process (Chandel, 2021a; Chandel, 2021b; González-Marenco et al., 2024). The pyruvate molecules are then transported to the mitochondria for pyruvate oxidation, where they are converted into acetyl coenzyme A (Acetyl-CoA).

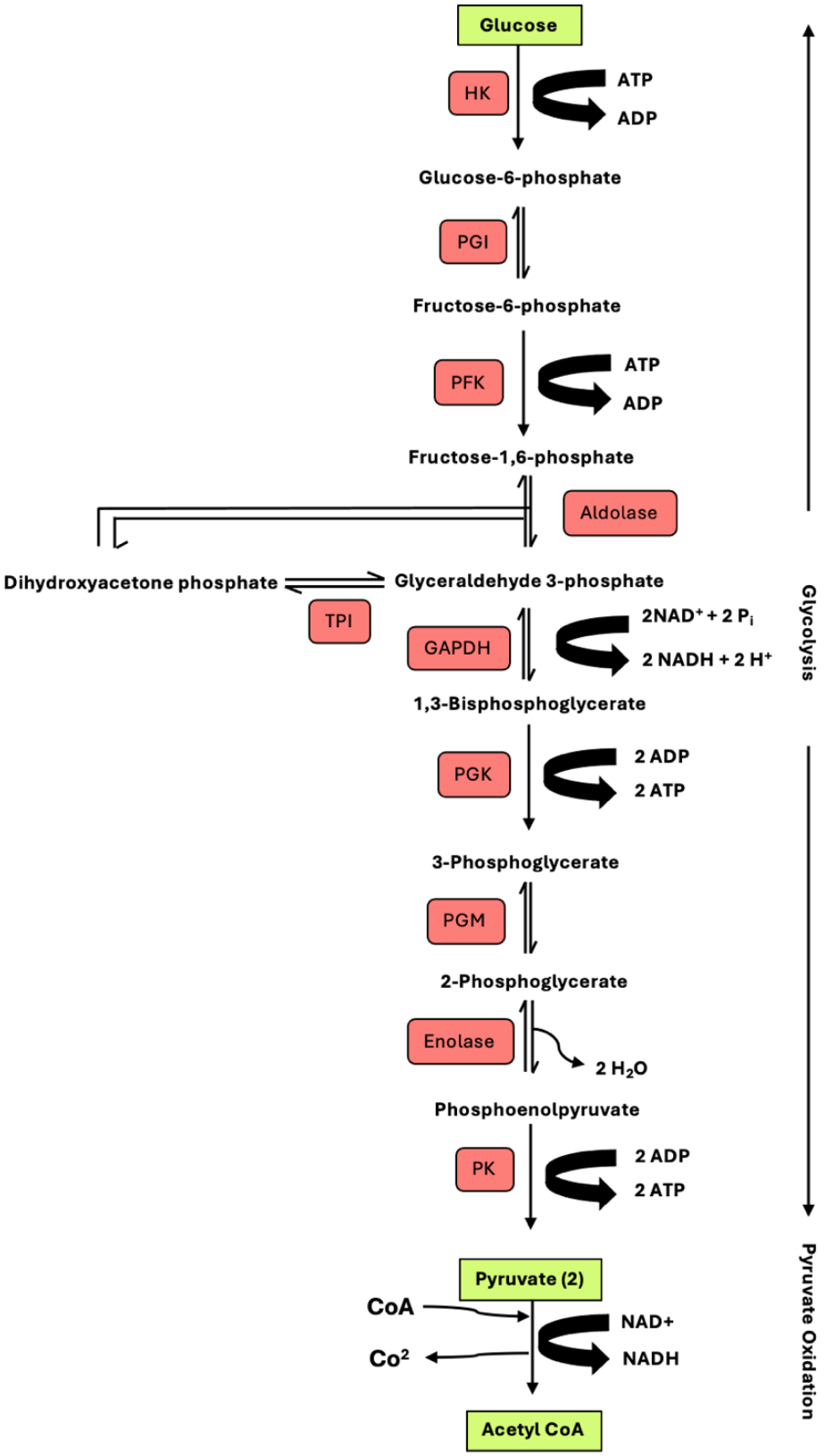

Figure 1. Stages of Glycolysis and Pyruvate Oxidation. Enzyme key: HK = Hexokinase. PGI = Phosphoglucose Isomerase. PFK = Phosphofructokinase. TPI = Triose Phosphate Isomerase. GAPDH = Glyceraldehyde-3-Phosphate Dehydrogenase. PGK = Phosphoglycerate Kinase. PGM = Phosphoglycerate Mutase. PK = Pyruvate Kinase. CoA = Coenzyme A. Information and figure adapted from Chandel, 2021a and Chandel 2021b.

Acetyl-CoA then enters the tricarboxylic acid (TCA) cycle, where it is oxidised to produce electron carriers: Nicotinamide adenine dinucleotide (NADH) and Flavin adenine dinucleotide ($FADH_2$), which are then used in the electron transport chain to generate ATP (Chandel, 2021a, Chandel, 2021b).

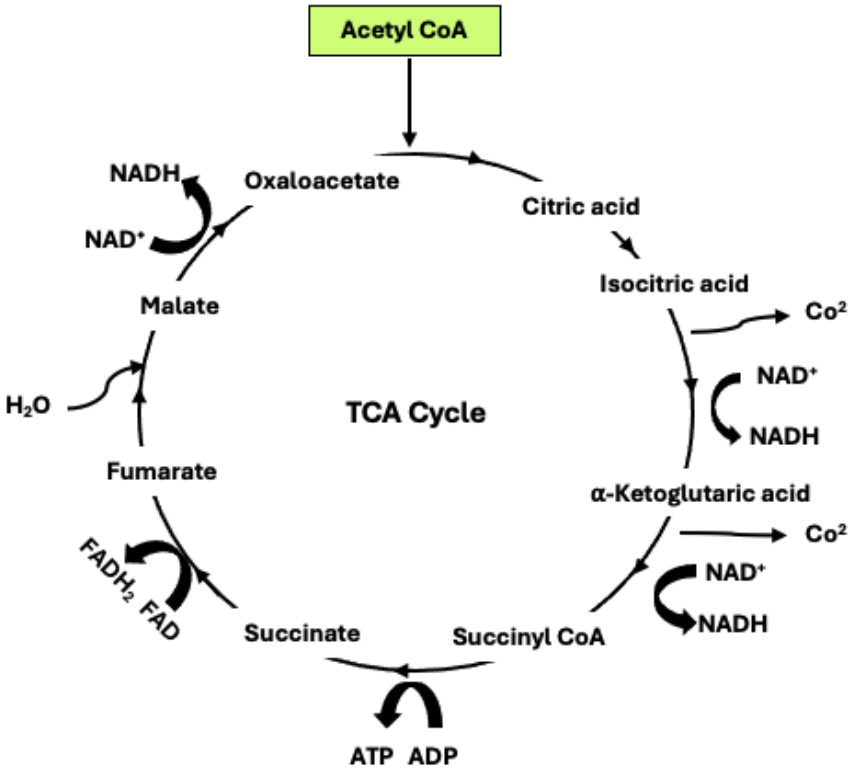

Figure 2. Tricarboxylic Cycle (TCA Cycle). Information and figure adapted from Chandel 2021a and Chandel 2021b.

In the electron transport chain, NADH donates electrons to Complex I, while $FADH_2$ donates electrons to Complex II. These electrons are then transferred through a series of redox reactions along the electron transport chain, creating an electrochemical proton gradient. This gradient is used to synthesise ATP via chemiosmosis, where protons pass through ATP synthase, allowing for the formation of ATP (Chandel, 2021a, Chandel, 2021b). This process ultimately produces 30-32 molecules of ATP, which fuel muscle contractions and physical activity. However, this theoretical ATP yield does not always translate directly to

practical performance benefits, as factors such as mitochondrial efficiency, substrate availability, and individual metabolic variation can significantly impact ATP production (González-Marenco et al., 2024).

As the duration or intensity of exercise increases, glucose availability and glycogen stores in muscle and liver tissue become depleted, which can lead to reduced ATP production, fatigue, and decreased performance. Consequently, the consumption of carbohydrates in the form of nutritional supplements is a commonly used strategy to sustain energy availability and delay the onset of fatigue during exercise (Podlogar & Wallis, 2022). However, while carbohydrate supplementation is widely accepted as beneficial, the extent of its impact depends on factors such as the timing, composition, and quantity of intake (Baker et al., 2015; Podlogar & Wallis, 2022).

Carbohydrates, particularly in the form of glucose, are the primary fuel source for moderate-to-high-intensity exercise, playing a crucial role in maintaining blood glucose levels and sustaining energy availability. During prolonged or intense physical activity, muscle glycogen stores become progressively depleted, making the consumption of additional carbohydrates essential to maintain performance (Baur & Saunders, 2021). Energy supplements, such as bars, gels, or drinks, are specifically designed to deliver glucose rapidly into the bloodstream, bypassing the slower stages of carbohydrate digestion and metabolism (Jeukendrup & Jentjens, 2000, Reynolds et al., 2022, Naderi et al., 2023). While these products claim to enhance endurance and recovery, their real-world efficacy compared to whole-food sources remains a subject of debate.

The delivery and oxidation of carbohydrates during exercise have been the subject of decades of high-quality research. Early studies suggested that approximately 20 grams (g) of carbohydrates per hour were necessary to see improvements in endurance performance (Fielding et al., 1985; Maughan, Bethell & Leiper, 1996). As research progressed, higher intake levels (60 g/hour) were proposed to yield additional benefits. However, it was suggested that carbohydrate oxidation during exercise is limited to a maximum of 60 g per hour, beyond which the absorption capacity of the intestines and glucose transporters

becomes saturated (Jeukendrup & Jentjens, 2000; Rosset, Egli & Lecoultre, 2017).

To overcome this limitation, researchers proposed combining different carbohydrate types, such as glucose and fructose, to enhance absorption and improve endurance performance. Glucose and fructose are absorbed via distinct pathways: glucose via the sodium-glucose transporter 1 (SGLT1) and fructose via the glucose transporter 5 (GLUT5). This combination has been shown to increase carbohydrate oxidation rates and endurance performance. Jentjens & Jeukendrup (2005) found that a glucose-fructose mixture maintained a 50% higher carbohydrate oxidation rate during the final 90 minutes of cycling. However, ingesting large amounts (≥ 1.2 g/min) of glucose + fructose appears significantly beneficial only for highly trained athletes capable of sustaining high-intensity exercise for ≥ 2.5 hours and whose gastrointestinal tracts have adapted to handle higher carbohydrate intake (Murray, 2006; Jeukendrup, 2014; Martinez et al., 2023).

1.2 Methods to assess carbohydrate supplementation and its effects on exercise and metabolism

The effects of carbohydrate supplementation on exercise performance and metabolism can be assessed using a variety of physiological and biochemical methods.

1.2.1 Performance-based assessments

There are a range of performance-based tests that evaluate the practical implications of carbohydrate supplementation on a range of exercise modalities, intensities and durations. These include time trials, repeated sprint protocols, glycogen depletion protocols, and time-to-exhaustion tests (Wallis et al., 2005; Krings et al., 2017; Hearris et al., 2022; Gough et al., 2022; Archacki et al., 2024). This method of evaluating the effect of carbohydrate supplementation is directly relevant to athletes, potentially allowing for real-world application of a range of carbohydrate supplementation strategies. However, these are typically

conducted in tightly controlled laboratory environments and may not always cross over into practical scenarios.

1.2.2 Muscle biopsy

Muscle biopsies allow for direct measurement of muscle glycogen content and enzymatic activity before, during and after exercise (Bergström, 1962; Bergström, 1975). This provides insights into carbohydrate storage and utilisation at a cellular level, allowing researchers to see how different carbohydrate loads and compositions may affect performance and recovery (Russo et al., 2021; Stout et al., 2025). Muscle biopsies are the 'gold-standard' method for assessing muscle glycogen availability and utilisation but are highly invasive and typically are used in studies with smaller sample sizes than those using less invasive methodologies due to (i) the costs involved in subsequent analysis and (ii) testing the minimal viable number of participants for ethical reasons.

1.2.3 Oral glucose tolerance test

One common approach is the oral glucose tolerance test, which measures blood glucose response following carbohydrate ingestion (Chung et al., 2017). By measuring blood glucose levels at regular intervals after ingestion, researchers can compare the glycaemic response of different carbohydrate formulations. This method provides a controlled environment to assess glucose kinetics which is useful for evaluating differences between supplement types. There is also a degree of flexibility in the volume of carbohydrates consumed, duration of the oral glucose tolerance test, and even how the blood is sampled, with some opting for arterialised venous blood sampling, and others for venous blood sampling (Hengist et al., 2017; Wrench et al., 2024). However, the oral glucose tolerance test does not account for the effects of exercise on glucose metabolism and may not fully represent real-world conditions where athletes consume carbohydrates during physical activity.

1.2.4 Indirect calorimetry

Indirect calorimetry measures oxygen consumption and carbon dioxide production to estimate substrate oxidation rates, allowing researchers to

determine whether carbohydrates or fats are the primary fuel sources. This is typically determined via equations which calculate the Respiratory Exchange Ratio (RER) or Respiratory Quotient (RQ), which describes the ratio of carbon dioxide output to oxygen consumption (Melzer, 2011; Glaab & Tuabe, 2022). An RER or RQ of 1 indicates carbohydrate oxidation, while a value of ≤ 0.7 indicates a greater reliance on fatty acid oxidation (Melzer, 2011). Indirect calorimetry can, therefore, be used to infer how different carbohydrate supplements affect metabolic responses. During exercise, especially at high intensities, the significant rise in oxygen consumption and carbon dioxide production can compromise the accuracy of indirect calorimetry. Factors like hyperventilation, acid-base imbalances, and non-metabolic CO_2 production can artificially elevate RER values, potentially leading to misinterpretations of substrate utilisation. Acid-base imbalances, including the buildup of lactate and excess hydrogen ions from anaerobic metabolism, trigger bicarbonate buffering, which increases CO_2 production independently of substrate oxidation (de Oliveira et al., 2022; Mitchell et al., 2024).

1.2.5 Continuous glucose monitoring

Continuous glucose monitoring provides real-time glucose readings, offering a dynamic understanding of blood sugar fluctuations (Wrench et al., 2024). Often measured every few minutes, continuous glucose monitors provide a non-invasive method of sampling interstitial fluid, an indicator of blood glucose, allowing researchers and athletes to monitor the effects of carbohydrate supplementation over time. However, these are less accurate than directly measuring the blood and require sensitive calibration to ensure accurate readings. Continuous glucose monitors have also been shown to underestimate the postprandial rise in glucose concentration in healthy subjects and may be overestimated during steady-state exercise (Wrench et al., 2024).

1.2.6 Gastrointestinal comfort

Carbohydrate supplementation can cause gastrointestinal discomfort, which can impair exercise performance (Gaskell et al., 2023; Gough et al., 2024). Researchers often assess gastrointestinal distress via subjective questionnaires

or a visual analogue scale (Bengtsson et al., 2011; Pfeiffer et al., 2012; Gaskell et al., 2023) to see how well individuals tolerate different quantities (e.g., high or low), formulations (e.g., bars, gels, drinks) or compositions (e.g., glucose, glucose-fructose, maltodextrin) of carbohydrate supplements. This provides important practical insights into supplement tolerability, helping to determine real-world applicability (King et al., 2020; Gough et al., 2024). However, due to its subjective nature, it may be harder to standardise findings using such measures.

1.3 Gaps in research on commercial carbohydrate supplements

Despite extensive research, gaps remain in understanding the real-world efficacy of commercially available carbohydrate supplements. Most studies focus on metabolic mechanisms rather than comparing commercially available carbohydrate product formulations and delivery methods under practical conditions. Additionally, the commercial supplement market varies widely in terms of composition, dosage, and cost, leaving consumers with limited independent guidance. The lack of systematic research comparing the performance of these products across diverse athletic populations highlights a critical limitation for consumers of these supplements.

Furthermore, the choice between energy bars, gels, and drinks can also overwhelm consumers. The research suggests that carbohydrate supplementation should be more personalised, dependent on exercise duration, intensity, and personal preference (Jeukendrup, 2014; Podlogar & Wallis, 2022), but the different formulations of carbohydrate supplements make meeting these demands confusing for consumers.

Energy gels provide quick, easily digestible carbohydrates. It was previously thought gels might require water for digestion and could cause gastrointestinal discomfort (Saunders et al., 2007; Pfeiffer et al., 2009), however, more recent research shows limited gastrointestinal discomfort, even when consuming carbohydrate energy gels at 120 g/h (Hearris et al., 2022). Energy drinks often combine carbohydrates, electrolytes, and water, offering hydration and energy,

but may provide less concentrated carbohydrates than gels (Jeukendrup, 2013). Energy bars are a less common alternative to gels and drinks. Due to their solid form, bars may be less convenient than gels or drinks, requiring chewing during exercise, which may also increase gastrointestinal discomfort (Guillochon & Rowlands., 2017). However, research demonstrates comparable energy availability and performance metrics between bars, gels and drinks (Pfeiffer et al., 2010; Guillochon & Rowlands., 2017). Given these subtle differences, further research is needed to compare their effectiveness and provide clearer recommendations for consumers.

This research intends to address these gaps by evaluating the efficacy of three popular commercially available carbohydrate supplements. Specifically, it seeks to investigate differences in carbohydrate formulations, comparing bars to gels and glucose-fructose mixtures to maltodextrin-based supplements. By providing evidence-based insights, the findings of these studies should help consumers make informed decisions about carbohydrate supplementation for athletic performance.

1.4 Aims & objectives

This thesis aims to investigate the efficacy of commercially available carbohydrate supplements by assessing their impact on glucose appearance in the bloodstream, and how this may translate into improved exercise performance.

The specific objectives of this research are to:

1. Compare the rate of glucose appearance in the bloodstream following ingestion of three different commercially available carbohydrate supplements: a glucose-fructose-based energy bar, a fructose-glucose hydrogel, and a maltodextrin-based gel.
2. Evaluate whether the different carbohydrate compositions impact high-intensity exercise performance.
3. Provide consumers of carbohydrate energy supplements with an evidence-based comparison of three popular products, informing their choices when consuming such products.

1.5 Research questions

1. How does the speed of glucose appearance in the bloodstream differ between a glucose-fructose energy bar, a fructose-glucose hydrogel, and a maltodextrin-based gel?
2. How do differences in carbohydrate composition affect energy availability and substrate utilisation in Tier 2 athletes?
3. Do differences in glucose absorption rates influence high-intensity exercise performance?
4. Do different commercially available carbohydrate supplements influence performance during maximal sprint efforts?

1.6 Structure of the thesis

This thesis is structured as two independent but related research studies, presented in separate chapters (Chapter 2 and Chapter 3).

Chapter 2 presents the first study, which investigates the speed at which glucose appears in the bloodstream following the ingestion of three commercially available carbohydrate supplements. This study uses a modified oral glucose tolerance test to provide a controlled assessment of how different carbohydrate formulations influence blood glucose concentration and substrate oxidation at rest.

Chapter 3 builds upon the findings of Chapter 2 by evaluating the impact of the same commercially available carbohydrate supplements on intermittent high-intensity exercise. This study examines whether differences in glucose absorption influence energy availability and the ability to sustain high-intensity efforts.

2. CHAPTER 2: Comparative analysis of carbohydrate delivery speeds of a glucose-fructose energy bar, a fructose-glucose hydrogel, and a maltodextrin-based gel in athletes.

2.1 Abstract

This study investigated the speed of carbohydrate delivery from three products in a double-blind randomised design: a glucose-fructose energy bar (Voom Pocket Rocket; VOOM), a fructose-glucose hydrogel (Maurten Gel 160; MAU), and a maltodextrin-based gel (SIS Go Isotonic; SIS). Sixteen healthy male Tier 2 athletes (aged 23 ± 4.2 years; height 182.03 ± 6.5 cm; weight 79.5 ± 8.3 kg; BMI 23.81 ± 1.2 kg/m²) completed a modified 60-minute oral glucose tolerance test. Subjects ingested 45 g of carbohydrates from VOOM, MAU, or SIS across three study visits. Resting blood samples were collected following a 2-hour fast and then at 5-minute intervals across 60 minutes for glucose, lactate and electrolytes (sodium, potassium, chloride), and every 10 minutes for insulin. Substrate utilisation was assessed using indirect calorimetry. Total carbohydrate oxidation was significantly greater in VOOM than SIS (24.6 ± 7.4 g vs 17.8 ± 8.6 g, $p = 0.01$) but not MAU (20.1 ± 6.4 g, $p > 0.05$). Conversely, total fat oxidation was lower for VOOM compared to SIS (7.37 ± 2.29 g vs 9.5 ± 3.4 g, $p = 0.007$) but not MAU (8.45 ± 3.36 g, $p > 0.05$). No significant differences were observed in peak glucose levels (VOOM 6.6 ± 1.2 mmol/L, MAU 6.2 ± 1.1 mmol/L, SIS 6.4 ± 1.15 mmol/L, $p > 0.05$) or time to glucose peak (VOOM 31.3 ± 14.0 min, MAU 39.1 ± 12.3 min, SIS 33.1 ± 11.1 min, $p > 0.05$). Insulin concentrations increased over time ($p < 0.0001$) but did not differ between products ($p > 0.05$). Electrolyte levels were consistent across products ($p > 0.05$). These results suggest that VOOM delivers carbohydrates as quickly, if not faster, than maltodextrin or glucose-fructose gels, making it an effective alternative for carbohydrate supplementation.

2.2 Introduction

Commercially available carbohydrate-rich energy supplements in the form of bars, gels, and drinks compete to provide a convenient source of quickly absorbed fuel that can be used by an athlete during exercise. The faster carbohydrates can be broken down, oxidised, and transported to muscles to generate adenosine triphosphate (ATP), the more optimal the performance benefit. Energy supplements, such as bars, gels, and drinks, are often formulated with monosaccharides like glucose and fructose, or polysaccharides like maltodextrin, which differ from the carbohydrates found in foods like rice or oats (Holesh et al., 2023).

Due to their simpler molecular structures, monosaccharides (e.g., glucose, fructose), disaccharides (e.g., sucrose), and certain high glycaemic index polysaccharides (e.g., maltodextrin) require little enzymatic breakdown. While mechanical digestion (chewing) contributes to breaking down food particles, the primary site of absorption is the small intestine (Rollo et al., 2020, Gromova et al., 2021; Holesh et al., 2023).

Monosaccharides are absorbed directly into the bloodstream, resulting in a rapid spike in blood glucose. Glucose is transported to the enterocytes (intestinal cells) via the sodium-glucose co-transporter 1 (SGLT1) and then exits the enterocytes into the bloodstream via the glucose transporter 2 (GLUT2). Fructose uses a slightly different pathway, entering the enterocytes via GLUT5, but also exits via GLUT2 (Hantzidiamantis et al., 2024).

Disaccharides, like sucrose, are hydrolysed by enzymes like sucrase-isomaltase, located on the surface of enterocytes, into their component monosaccharides (glucose and fructose) (Chandel, 2021a, Holesh et al., 2023). These monosaccharides are then absorbed via the pathways outlined above. Similarly, polysaccharides like maltodextrin, which have a low degree of polymerisation, meaning they consist of short glucose chains formed by linking individual glucose molecules together, are initially broken down by amylase from the saliva and pancreas into smaller oligosaccharide chains. These smaller chains are further

hydrolysed by enzymes located on the enterocyte surface, such as maltase and isomaltase, releasing glucose molecules for absorption (Chandel, 2021a, Holesh et al., 2023).

Ultimately, the monosaccharides, disaccharides, and polysaccharides commonly used in energy supplements, like glucose, fructose, sucrose, and maltodextrin, are quickly digested, leading to a faster rate of absorption. This results in a rapid rise in blood glucose concentrations, further accelerated by their higher glycaemic index and low fibre content (Jeukendrup & Jentjens, 2000). The quick spike in blood glucose speeds up glucose oxidation via glycolysis and the tricarboxylic acid cycle, ultimately enhancing ATP production. For athletes, especially those completing long-duration activities such as a marathon, this rapid energy availability from carbohydrate-dense supplements like bars, gels, and drinks supports carbohydrate metabolism and helps to sustain exercise performance, delaying the onset of fatigue and minimising gastrointestinal discomfort compared to liquid sources like sports energy drinks or whole foods (Jeukendrup & Jentjens, 2000, Reynolds et al., 2022, Naderi et al., 2023).

Historically, it was suggested that as little as 20 grams (g) of carbohydrates per hour were sufficient to observe a performance benefit, with 22 g of carbohydrates per hour shown to elicit performance benefits during cycling bouts of 4 hours, elevating respiratory exchange ratio, blood glucose, and time to exhaustion (Fielding et al., 1985). Oxidation of carbohydrates from a single source like glucose seemed to be limited to 60 g per hour (Jeukendrup & Jentjens., 2000), but more recent research indicates up to 90 g and even 120 g of carbohydrates per hour can be oxidised when carbohydrates are combined, such as glucose and fructose, due to being absorbed via independent transporters – glucose via SGLT1, and fructose via GLUT5 – and may vary based on body size, with larger athletes potentially requiring higher carbohydrate intake to optimise performance (Currell & Jeukendrup., 2008, Triplett et al., 2010, Jeukendrup, 2013, King et al., 2018, Viribay et al., 2020, Baur & Saunders, 2021, Podlogar et al., 2022, Ijaz et al., 2024).

How athletes consume such high volumes of energy requires strategic and individualised nutrition plans and constant fuelling from convenient energy sources, which cause minimal gastrointestinal discomfort and still provide an immediate source of energy (Podlogar & Wallis., 2022, Gough & Sparks, 2024). Energy bars, gels, drinks, and chews are utilised to provide carbohydrates, typically in volumes of 10-20 g, throughout exercise to meet these high energy demands. Comparisons between types of energy supplements show minimal differences in energy delivery, exercise capacity and gastrointestinal comfort. Pfeiffer et al. (2010) demonstrated the consumption of a solid glucose-fructose bar elicited similar peak carbohydrate oxidation rates to a glucose-fructose drink (Bar 1.25 ± 0.15 $g \cdot min^{-1}$ and Drink 1.34 ± 0.27 $g \cdot min^{-1}$) during 180 minutes of cycling. Similarly, Hearris et al. (2022) demonstrated comparable high rates of carbohydrate oxidation from solid (jelly chew), semisolid (gel), fluid (drink), and a combination of the forms (mix) during 180 minutes of cycling and an exercise capacity test. Peak carbohydrate oxidation was similar across all three forms (Chew 1.59 ± 0.08, Gel 1.58 ± 0.13, Drink 1.56 ± 0.16, Mix 1.66 ± 0.02 $g \cdot min^{-1}$). Furthermore, 40 g of a maltodextrin-fructose (2:1 ratio) carbohydrate energy gel was shown to reduce inflammatory markers and metabolic stress following a 15 km run at 90% VO_2 max intensity (Righetti et al., 2024).

To sustain carbohydrate availability throughout exercise, novel supplements like carbohydrate hydrogels can be utilised. Hydrogels target two commonly referenced rate-limiting factors for carbohydrate delivery: gastric emptying and intestinal absorption (King et al., 2020; Baur & Saunders, 2021; Rowe et al., 2022). Gastric emptying refers to the rate at which food leaves the stomach and enters the small intestine, while absorption, the process by which nutrients are taken up from the digestive tract into the bloodstream, determines how efficiently nutrients are taken up into circulation (Mackie, 2024). Traditional carbohydrate solutions like sports energy drinks containing dissolved carbohydrates like glucose, fructose or maltodextrin, can slow gastric emptying due to high osmolality, potentially causing gastrointestinal discomfort. In contrast, hydrogels form a structured matrix upon contact with stomach acid, reducing osmolality and allowing for a faster gastric clearance while delivering carbohydrates in a form optimised for absorption (Rowe et al., 2022).

Rowe et al. (2022) investigated the effects of consuming 90 g/hour of a 2:1 glucose-to-fructose ratio in the form of a carbohydrate hydrogel or standard carbohydrate solution during a 120-minute steady-state run followed by a 5 km time trial. Time-trial performance improved by 2.1% with hydrogel ingestion (19:29 ± 2.24 min) compared to the carbohydrate solution (21:05 ± 2.34 min). Exogenous carbohydrate oxidation was also greater with the hydrogel (68.6 ± 10.8 g) than with the carbohydrate solution (63.4 ± 8.1 g). Furthermore, Nielsen et al. (2024) compared time-to-exhaustion cycling performance following ingestion of a carbohydrate hydrogel. Cycling duration increased with ingestion of a carbohydrate-only hydrogel (29.1%) compared to a non-hydrogel solution. Both studies reported no or very mild gastrointestinal discomfort when ingesting carbohydrate hydrogels. However, several studies have reported no performance or gastrointestinal benefits from the addition of hydrogels to carbohydrate beverages (Minichello, 2022; Sutehall et al., 2022a; Sutehall et al., 2022b).

While research has demonstrated the beneficial effects of carbohydrate supplementation on exercise performance, few studies have compared the difference in speed glucose appears in the bloodstream between different commercially available brands, with previous studies typically comparing non-branded or within the same brand. This study will provide insight into the speed at which commercially available energy supplements provide energy by comparing the difference in energy delivery between a glucose-fructose-based energy bar, a fructose-glucose hydrogel, and a maltodextrin-based gel, giving insight into nutritional strategies for both amateur and elite athletes alike.

2.3 Aim of the research

This study aimed to investigate the speed glucose appears in the bloodstream between three commercially available carbohydrate supplements in a double-blind, randomised crossover design.

2.4 Methods

2.4.1 Subject recruitment

Subjects were recruited through local sports clubs, social media, and posters, contacted to discuss the study and eligibility criteria, and, if deemed suitable, provided with an information sheet and an in-person screening date.

2.4.2 Subjects

A sample of seventeen Tier 2 (McKay et al., 2021) male runners, cyclists, and triathletes aged 18-35 years old were recruited from local and university sports clubs and gave written informed consent to take part. One subject chose to withdraw due to mild discomfort associated with the cannulation procedure, leaving sixteen subjects to complete all three study visits. The risks, benefits and requirements for each study visit were outlined to all subjects, and they had an opportunity to ask questions before providing written informed consent. This was a preregistered trial (NCT06375577) that received ethical approval from Lancaster University Medical School (ethics number: LMS-24-Dean-1) and was conducted in the Human Performance Laboratory at Lancaster University. All testing was done in accordance with the Declaration of Helsinki and Good Clinical Practice. Subject characteristics are detailed in Table 1.

Table 1: Subject demographics (mean ± SD)

	Males (12 runners, 1 cyclist, 3 triathletes)
Age (years)	23 ± 4.2
Height (cm)	182.03 ± 6.5
Weight (kg)	79.5 ± 8.3
BMI (kg/m^2)	23.81 ± 1.2
Lean mass (kg)	65.8 ± 5.4
Body fat (%)	14.5 ± 5.0

BMI - Body Mass Index

2.4.3 Medical screening

Subjects included healthy males aged 18-35 years, classified as Tier 2 runners, cyclists, or triathletes (McKay et al., 2021), with a Body Mass Index (BMI) of 18.5-24.9 kg/m² based on NHS-defined healthy ranges and prior research on athletes' BMI (Knechtle et al., 2011; Marc et al., 2014; Heller et al., 2022; NHS, 2022). Subjects attended the Human Performance Laboratory at Lancaster University and completed a medical screening form aligned to the American College of Sports Medicine (ACSM) safety-to-exercise guidelines (Liguori, 2020) to confirm no contraindications or allergies to study supplements. Subjects were excluded if they had any medical conditions, took medications, or adhered to diets affecting gut microbiome glucose responses, including high-carbohydrate-low-fat (HCLF), low-carbohydrate-high-fat (LCHF), and ketogenic and glycogen manipulation diets (Rauch et al., 2022). Subjects refrained from caffeine, drugs, alcohol, and strenuous exercise for 24 hours before screening and study visits. Height and body mass were measured using an ultrasonic stadiometer and scales (217 ultrasonic stadiometer and scales, Seca, Hamburg, Germany), while body composition was assessed with a Tanita DC-430P (Tanita, Tokyo, Japan).

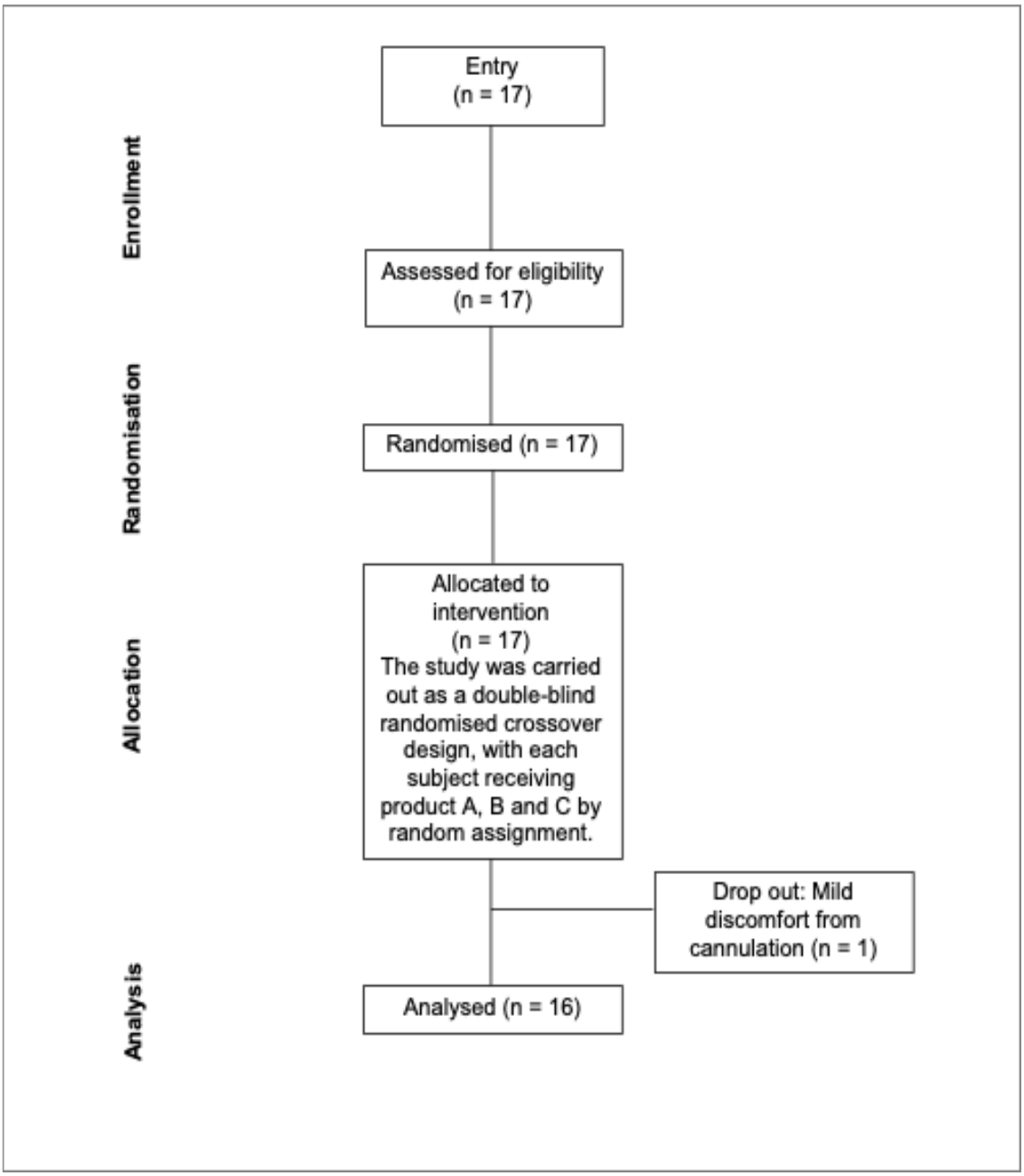

Figure 3. CONSORT flow chart and study design. A double-blind randomised crossover design.

2.4.4 Supplement administration

The supplements compared in this study were the Voom Pocket Rocket Electro Energy Bar (VOOM), Maurten Gel 160 (MAU), and Sport in Science Go Isotonic Energy Gel (SIS). Nutritional information can be seen in Table 2. Supplement administration was conducted in a double-blind and randomised manner. Each supplement was carefully matched to provide 45 g of carbohydrates. All supplements were prepared by a laboratory technician certified in food hygiene. Supplements were prepared and randomised by the laboratory technician using an online randomisation tool (Research Randomiser: https://www.randomizer.org). Neither the participants nor the researchers involved in data collection and analysis knew which supplements were being consumed. The laboratory technician was not involved in analysing the data, maintaining blinding throughout the study. The supplements were provided to the subjects 15 minutes before testing began by the laboratory technician in clear plastic bowls. The laboratory technician weighed the supplements before and after consumption to ensure all 45 g of carbohydrates had been consumed (this equates to 47 g of VOOM, 73.125 g of MAU, and 122.7 g of SIS). Subjects consumed 49.94 ± 2.79 g of VOOM, 74.56 ± 1.55 g MAU 122.81 ± 1.28 g SIS.

Table 2: Nutritional information of energy supplements consumed

Supplement	Ingredients	Nutritional information (matched for 45 g carbohydrate)
VOOM	Raw Cane Sugar, Glucose Syrup, Water, Dried Fruit (1%), Electrolytes (Tri-sodium Citrate, Pink Himalayan Salt, Potassium Chloride, Magnesium Oxide, Calcium Lactate) (0.3%), Natural Flavouring, B-Vitamins. No artificial sweeteners, thickeners or preservatives	176 kcal, 45 g carbohydrates, 41 g of which sugar, 0 g fat, 0 g protein, trace salt, 1 mg B-Vitamins, 120 mg electrolytes
MAU	Water, glucose, fructose, gelling agent: calcium carbonate, gelling agent: gluconic acid, gelling agent: sodium alginate	180 kcal, 45 g carbohydrates, 45 g of which sugars, 0 g fat, 0 g protein, 90 mg salt
SIS	Water, Maltodextrin (from Maize) (33%), Gelling Agents (Gellan Gum, Xanthan Gum), Natural Flavouring, Acidity Regulators (Citric Acid, Sodium Citrate), Preservatives (Sodium Benzoate, Potassium Sorbate), Sweetener (Acesulfame K), Sodium Chloride, Antioxidant (Ascorbic Acid)	178 kcal, 45 g carbohydrates, 1.23 g of which sugars, 0 g fat, 0 g protein, 20 mg salt

2.4.5 Experimental visits

Subjects were required to complete three separate experimental visits separated by at least 48 hours. Subjects arrived at the Human Performance Laboratory following a 2-hour fast and having refrained from strenuous physical activity, caffeine, and alcohol for 24 hours prior. Subjects were asked to record their breakfast meal from the day of the first experimental visit and were asked to replicate this for each of the following two visits. Each experimental visit was scheduled for the same time of day ± 1 hour 30 mins. Upon arrival at the Human Performance Laboratory, subjects had their height and body mass measured (217 ultrasonic stadiometer and scales, Seca, Hamburg, Germany) before lying in a semi-supine position on a medical bed (Plinth 2000, Plinth Medical, Suffolk, UK) where the arm was prepped for cannulation. An antegrade venous cannula (Vasofix Safety IV Catheter 18G, BBraun, Sheffield, UK) was inserted into a superficial vein in the antecubital fossa by a member of the research team qualified in this procedure. Once secured in place, a three-way stopcock (Leur Splitter three-way Stopcock, Teqler, Wecker, Luxembourg) was inserted into the end of the cannula. Resting blood samples for glucose and lactate concentrations were taken using a 1 ml syringe and a 3 ml vacutainer for insulin. Subjects were then required to rest for 15 minutes to allow them to reach a relaxed state before the study began, as previously described in research measuring resting metabolic rate (Blannin & Wallis, 2024). To prevent blood from clotting in the cannula, the cannula was flushed using a saline solution (0.9% sodium chloride) every 15 minutes throughout the study visit. A saline flush log was kept for each visit. An average of 4.64 ± 0.74 ml of saline was administered across the study visits, with a small sample discarded after each flush to prevent any influence on metabolite concentrations.

2.4.6 One-hour modified oral glucose tolerance trial

After the 15-minute rest period, subjects were required to consume one of the three supplements. To standardise, subjects had 2 minutes to fully consume the supplement. Upon consumption, a Hans Rudolph face mask was fitted (Hans Rudolph 7450, Hans Rudolph, Kansas, USA). This was connected to an online gas analyser (Cortex Metalyzer 28-R3, Cortex, Leipzig, Germany) to measure

substrate utilisation via indirect calorimetry, recording the Respiratory Quotient (RQ), and calculating carbohydrate and fat oxidation rate via the volume of oxygen and carbon dioxide. The study timer was then set to 1 hour. Subjects were required to rest quietly throughout in a semi-supine position and could use a mobile device to keep them occupied. A schematic of the study design can be seen in Figure 4.

2.4.7 Blood sampling and storage

During each 1-hour experimental visit, 1 ml of blood was sampled every 5 minutes for glucose and lactate. This was sampled via a 1 ml syringe before being ejected onto a non-absorbent pad, which was then collected in a capillary tube to be analysed immediately using a benchtop blood analyser (Biosen C-Line GP+, EKF, Barleben, Germany). Every 10 minutes, 3 ml of blood was sampled for insulin. Once sampled, the 3 ml gold-top serum separator vacutainer (CAT Serum Sep Clot Activator, VACUETTE, Greiner-Bio One, Gloucestershire, UK) was inverted several times and left to clot at room temperature for 15 minutes before being spun in a centrifuge at 4°C, 1800 Relative Centrifugal Force (RCF), for 10 minutes. The supernatant was then transferred to a microfuge tube and stored at -20°C during the study before moving to -80°C after the study visit for analysis at a future date.

2.4.8 Electrolyte analysis

The supernatant was analysed for electrolyte content using an electrolyte analyser (i-smart 30 PRO, Woodley Laboratory Diagnostics, Bolton, United Kingdom). The supernatant was inserted into the tip of the electrolyte reader and analysed for sodium, potassium, and chloride.

2.4.9 Insulin measurement

The insulin levels were measured using an enzyme-linked immunosorbent assay (ELISA). Samples were prepared and analysed, and absorbance was read at both 450 nanometres (nm) and 630 nm before subtracting the 630 nm

absorbance readings from the 450 nm absorbance readings, following the manufacturer's protocol (Human Insulin ELISA Kit, CrsytalChem, Illinois, USA). Insulin concentrations are presented as micro-units per millilitre (μU/mL).

Due to some missing data points for insulin (VOOM = 10, MAU = 11, SIS = 8), a Monte Carlo simulation was conducted to address potential biases from incomplete observations (Schafer, 1997). This method generates multiple plausible imputations for the missing values based on the distribution of the observed data, ensuring that the underlying patterns within the dataset are preserved. By simulating a range of possible values, the approach reduces the risk of biased estimates that could arise from simpler imputation methods. Furthermore, using multiple imputations allows for a more accurate assessment of uncertainty, providing more reliable statistical estimates and leading to more robust conclusions regarding insulin measurements (Schafer, 1977; Dong et al., 2013; Austin & van Buuren, 2022).

To compare changes in glucose and insulin levels over time, data from both variables were normalised to a 0-100% scale to allow for meaningful comparisons, as they were measured in different units (glucose in mmol/L and insulin in μU/mL). The normalisation process involved calculating the percentage change from baseline for each participant at specified time points (every 10 minutes throughout the modified oral glucose tolerance test). The calculation used to calculate the normalised values are outlined below:

$$([\text{Current Value} - \text{Baseline Value}]/[\text{Maximum Value} - \text{Minimum Value}]) \times 100$$

2.4.10 Morphological parameters of the glucose curve

Time to glucose peak was determined as the point at which glucose reached its highest value during the modified 1-hour oral glucose tolerance test for each product. The shape of the glucose curve was classified as either monophasic or biphasic, following previously described methods but adapted to suit this modified 1-hour oral glucose tolerance test (Tschritter et al., 2003; Chung et al., 2017). A

curve was classified as monophasic if glucose increased to a maximum at any time during the test and then declined thereafter. A curve was classified as biphasic if glucose peaked followed by a nadir - the lowest glucose concentration observed after the initial peak - before rising again before the test's conclusion. Glucose shapes that reached a nadir after an initial increase and increased again > 0.25 mmol/L would be classified as biphasic (Tschritter et al., 2003; Chung et al., 2017). To further quantify the shape of the glucose response curves, the slope was calculated for each participant via simple linear regression using the feature on GraphPad Prism 10.4.1 (GraphPad Software, San Diego, CA, USA).

2.4.11 Substrate utilisation

Carbohydrate oxidation and fat oxidation ($g \cdot min^{-1}$) were calculated from the volume of oxygen ($\dot{V}O_2$) and carbon dioxide ($\dot{V}CO_2$) using the stoichiometric equations described by Frayn, (1963). These equations were chosen as they are commonly used to calculate carbohydrate and fat oxidation rates within resting studies, whereas the Jeukendrup & Wallis, (2005) equations are primarily used in exercise studies. The Frayn (1983) equations used were:

$$\text{Carbohydrate oxidation } (g \cdot min^{-1}) = 4.55 \times \dot{V}CO_2 \text{ (L/min)} - 3.21 \times \dot{V}O_2 \text{ (L/min)}$$

$$\text{Fat oxidation } (g \cdot min^{-1}) = 1.67 \times \dot{V}O_2 \text{ (L/min)} - 1.67 \times \dot{V}CO_2 \text{ (L/min)}$$

Carbohydrate oxidation efficiency (%) was calculated using the below formula:

[(Total carbohydrate oxidised/carbohydrate ingested (45 g)]*100

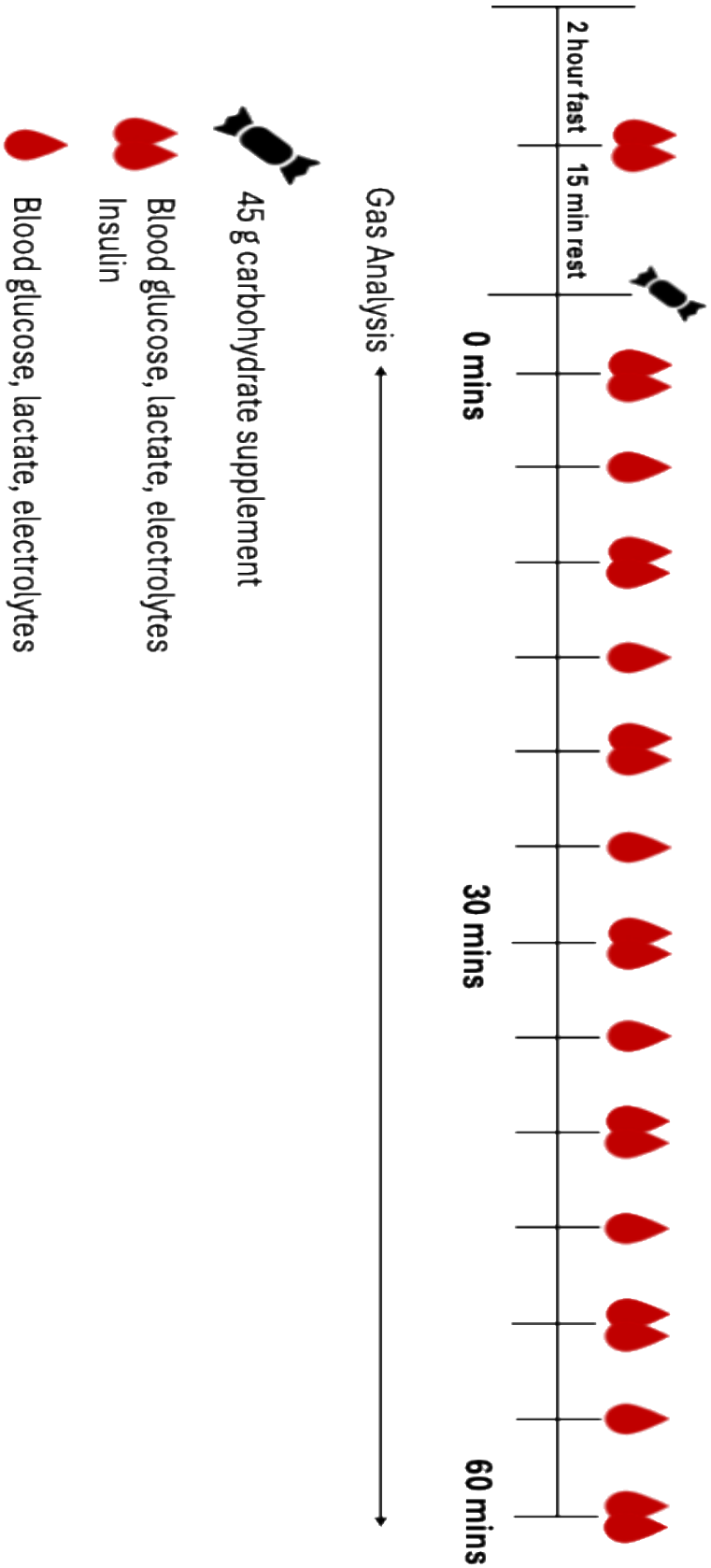

Figure 4. Schematic of study design

2.5 Statistical analysis

Data were tested for normality using Shapiro-Wilk tests. The mean and standard deviation (SD) are reported unless otherwise stated. Time-series data for normally distributed variables were analysed using repeated measures ANOVA with product and time as within-subject factors. Where there was a significant main effect for treatment (Product), time, or interaction, the location of differences was further probed using the Tukey post-hoc test. Non-normally distributed variables were analysed using Friedman's test. Where there was a significant main effect for treatment (Product), time, or interaction, the location of differences was further probed using Dunn's post-hoc comparison tests. Both were corrected using Bonferroni adjustments to account for multiple comparisons. Data analysis and figure preparation were conducted using GraphPad Prism 10.4.1 (GraphPad Software, San Diego, CA, USA). Significance was defined as $p < 0.05$.

2.6 Results

2.6.1 Comparable glucose uptake across the three nutritional supplements

Resting blood glucose levels were similar for all three products: VOOM (4.50 ± 0.67 mmol/L), MAU (4.50 ± 0.53 mmol/L), and SIS (4.41 ± 0.39 mmol/L), with no significant difference between them ($p = 0.7$). Glucose concentrations remained similar throughout the trial, as shown in Figure 5., with no statistical differences found between the products ($p > 0.05$).

Based on the classifications for monophasic and biphasic glucose response curves, all three products (VOOM, MAU, SIS) exhibited monophasic curves, where glucose levels rose to a maximum and then declined. While VOOM displayed characteristics of a biphasic curve, with a rise after the initial decline, the second increase was insufficient (0.14 mmol/L) to meet the 0.25 mmol/L threshold for biphasic classification (Tschritter et al., 2003; Chung et al., 2017).

To further quantify the glucose response curves, the slope was calculated for each participant using simple linear regression. Visual inspection of the curves indicated a similar pattern across VOOM, MAU, and SIS from rest to 10 minutes, which was confirmed by no significant differences in the slopes between rest and 10 minutes (VOOM 0.002 ± 0.01; MAU 0.006 ± 0.01; SIS 0.003 ± 0.01, $p = 0.8$). Upon visual inspection at the 10-minute mark, VOOM and MAU showed a steeper increase in glucose levels compared to SIS. To quantify this, simple linear regression was used to measure the glucose response slopes from 10 minutes to peak for each product. A one-way repeated measures ANOVA revealed a trend toward significance between products ($p = 0.06$). Post-hoc analysis with Tukey's multiple comparisons test showed a significantly greater slope in VOOM (0.06 ± 0.04) compared to MAU (0.03 ± 0.02, $p = 0.008$). No significant differences were found between SIS and VOOM, or between SIS and MAU (SIS; 0.06 ± 0.05).

No significant differences were shown in the rate of change in glucose between products (VOOM 0.006 ± 0.04 mmol/L/min, MAU 0.011 ± 0.04 mmol/L/min, SIS 0.008 ± 0.05 mmol/L/min, $p = 0.7$), and the area under the curve was similar for all three products (total area ± standard error) (VOOM 314.3 ± 12.45, MAU 317.2 ± 12.10, SIS 316.50 ± 12.04), reflecting comparable total glucose exposure over time with no significant differences found between products.

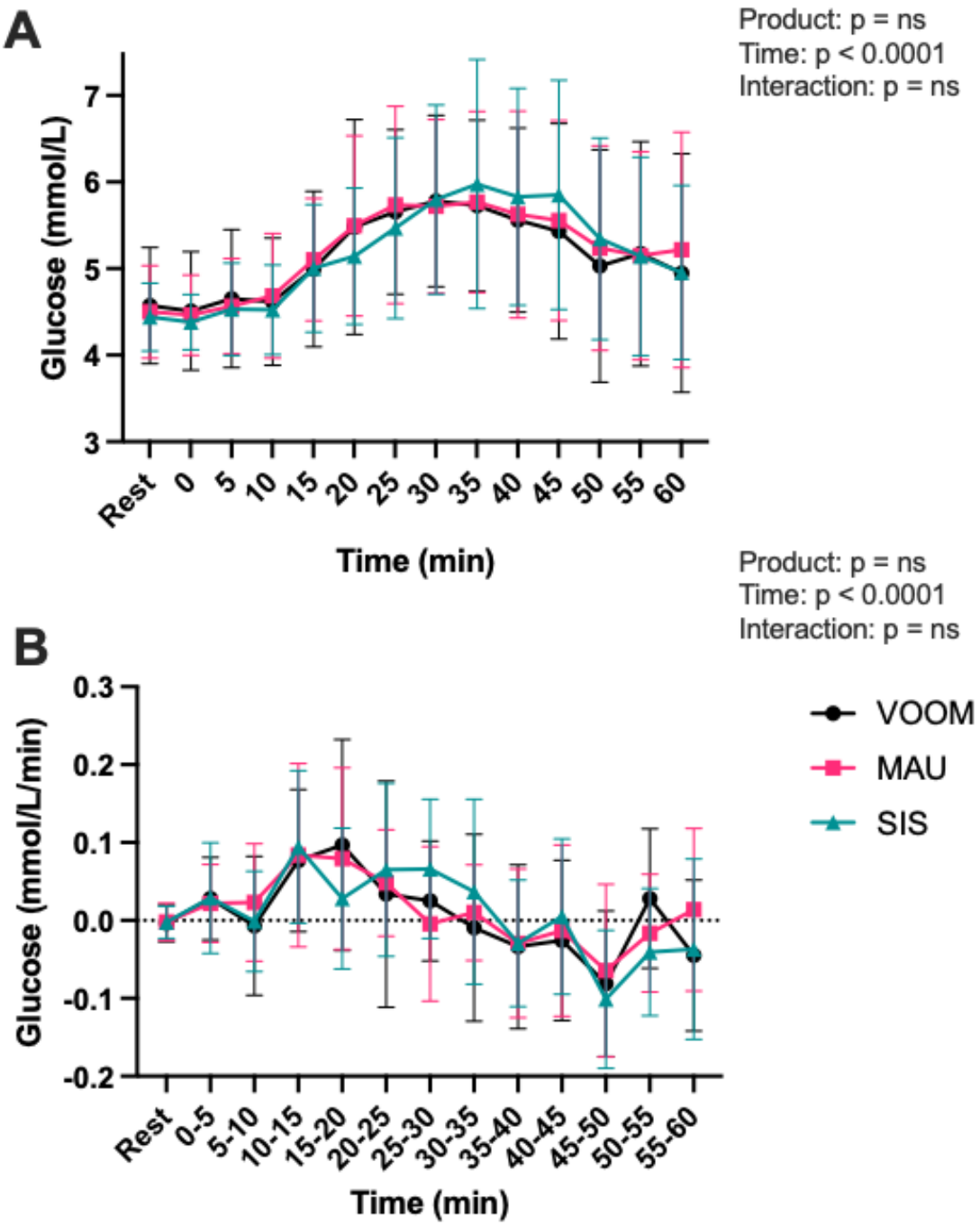

Figure 5. (A) Glucose response curves for VOOM, MAU, and SIS. All curves were classified as monophasic due to glucose increasing to a maximum and then declining thereafter. (B) The rate of change in glucose was similar between products.

Mean peak glucose concentration (VOOM 6.59 ± 1.18, MAU 6.20 ± 1.14 mmol/L, SIS 6.42 ± 1.15 mmol/L) and time to glucose peak (VOOM 31.25 ± 13.96 min, MAU 39.06 ± 12.28 min, SIS 33.13 ± 11.09 min) also showed no statistical significance between products ($p > 0.05$).

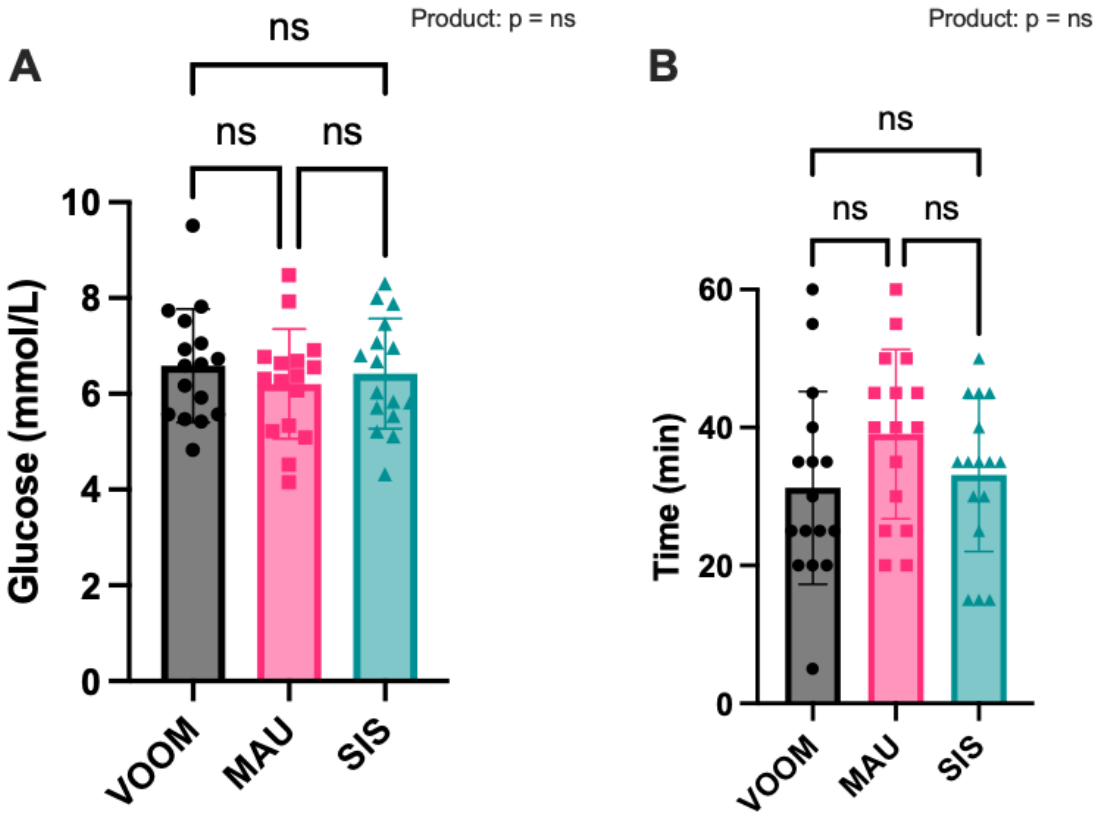

Figure 6. (A) Peak glucose concentrations were comparable across the three products. (B) No significant differences in time to glucose peak ($p > 0.05$).

2.6.2 Insulin was not different between products

Insulin levels before supplement ingestion (baseline) did not significantly differ between products (VOOM 11.15 ± 12.05 µU/mL; MAU 13.77 ± 27.26 µU/mL; SIS 8.174 ± 10.63 µU/mL, $p = 0.5$).

To analyse the insulin data, a two-way repeated measures ANOVA was conducted. A significant effect of time was found ($p < 0.0001$) but no product or interaction effect was present for insulin levels between VOOM, MAU or SIS ($p >$

0.05). VOOM elicited a greater area under the curve (total area ± standard error) (185.8 ± 43.77) than MAU (156.7 ± 44.76) and SIS (121.4 ± 29.35), indicating a greater or more prolonged insulin response when consuming VOOM.

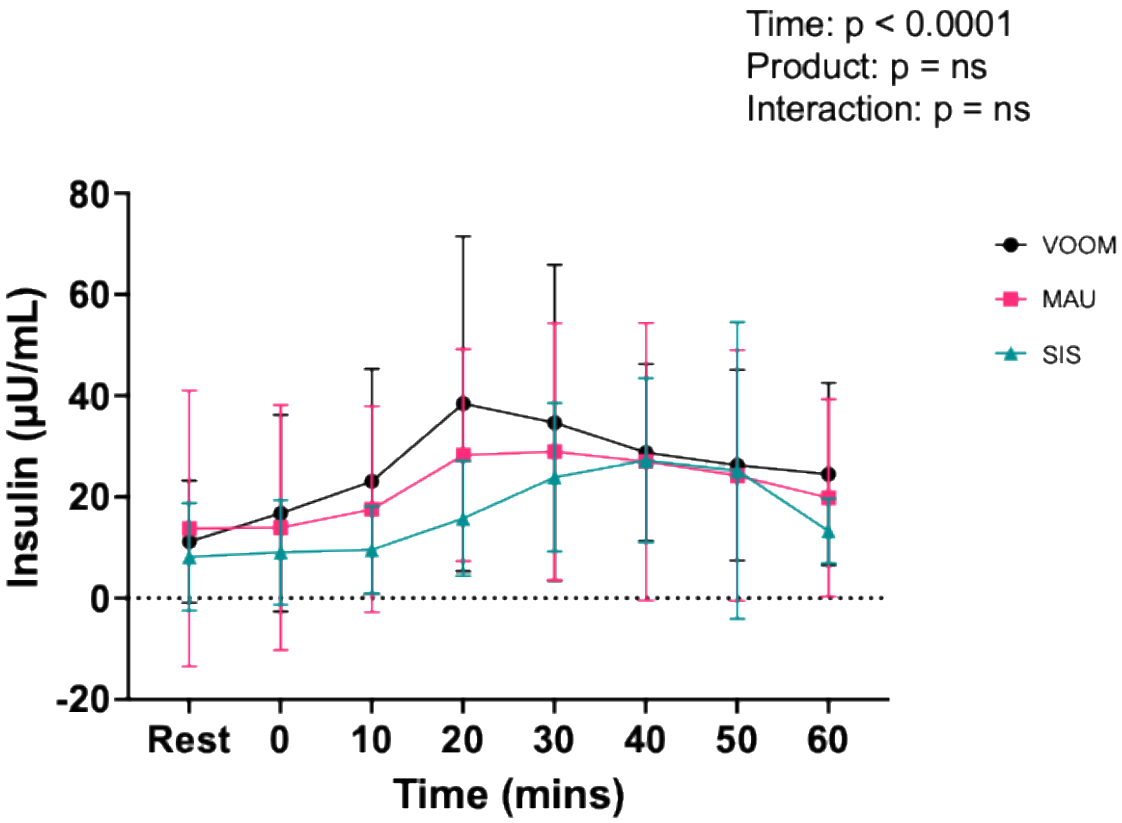

Figure 7. Insulin levels were not significantly different between VOOM, MAU, or SIS.

Following normalisation, the relative changes in glucose and insulin over time were compared. Both variables were presented as percentage changes from baseline (0%) and plotted for each participant every 10 minutes across the 1-hour modified oral glucose tolerance test. A two-way repeated measures ANOVA revealed no significant differences between glucose and insulin concentrations across any product ($p > 0.05$), with only an effect of time being present ($p < 0.0001$).

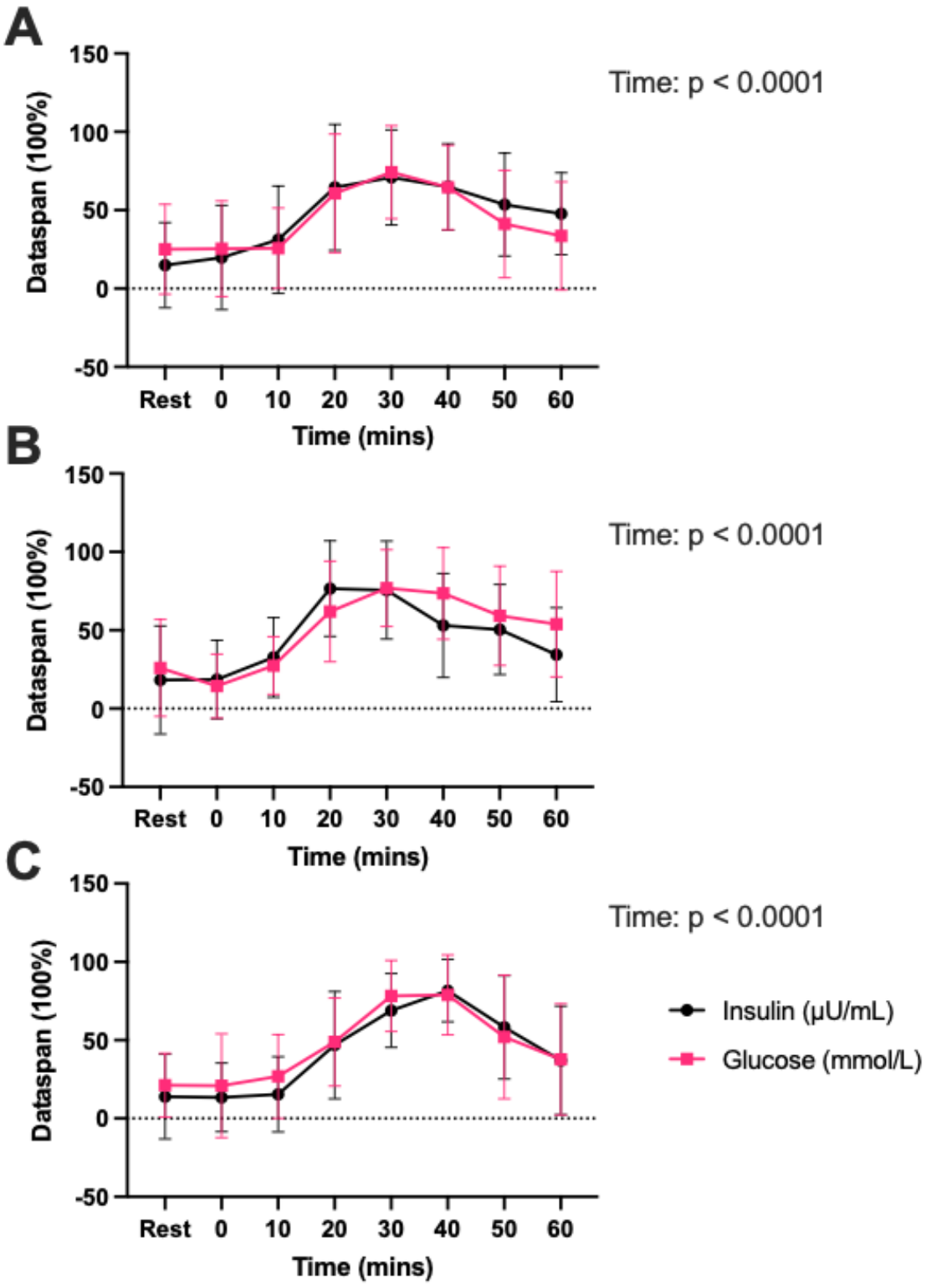

Figure 8. Normalised (data span = 100%) mean ± SD comparisons between insulin and glucose in response to 45 g carbohydrate showed no difference between insulin and glucose for (A) VOOM, (B) MAU, or (C) SIS.

2.6.3 VOOM enhances carbohydrate oxidation

A Friedman test was conducted to evaluate differences in the Respiratory Quotient (RQ) as the data was non-normally distributed. The Friedman test ranks data based on the relative position of each observation within its matched dataset. The results indicated significant differences in RQ among the products, X^2 (38) = 187.8, $p < 0.0001$. VOOM had a greater mean rank (24) than MAU (18) and SIS (16), indicating greater RQ. The raw data means for RQ were greater for VOOM (0.86 ± 0.06) than MAU (0.84 ± 0.07) and SIS (0.83 ± 0.07), suggesting a marginally greater reliance on carbohydrate metabolism when consuming VOOM. Dunn's multiple comparisons test was used for post-hoc pairwise comparisons, with a Bonferroni correction applied to account for multiple comparisons, revealing no significant differences between products.

Total carbohydrate oxidation significantly differed between products ($p = 0.01$). Tukey's multiple comparisons revealed that VOOM had significantly greater total carbohydrate oxidation than SIS (VOOM 24.63 ± 7.38 g, SIS 17.77 ± 8.61 g, $p = 0.01$). No differences were observed between MAU and either VOOM or SIS (MAU 20.11 ± 6.41 g, $p > 0.05$). VOOM had greater carbohydrate oxidation efficiency, oxidising 54.7% of the 45 g carbohydrates consumed, compared to 44.7% for MAU and 39.5% for SIS.

A significant main effect was observed for both time ($p < 0.0001$) and product ($p = 0.04$) on carbohydrate oxidation per minute. VOOM had a greater mean carbohydrate oxidation rate (0.27 ± 0.05 $g \cdot min^{-1}$) than MAU (0.21 ± 0.05 $g \cdot min^{-1}$) and SIS (0.19 ± 0.06 $g \cdot min^{-1}$). Tukey's multiple comparisons showed that at 15 minutes, VOOM had a significantly greater carbohydrate oxidation rate per minute than SIS (VOOM 0.25 ± 0.15 $g \cdot min^{-1}$; SIS 0.12 ± 0.07 $g \cdot min^{-1}$, $p = 0.019$). At 40 minutes, VOOM had a significantly greater carbohydrate oxidation rate per minute than both MAU (VOOM 0.32 ± 0.09 $g \cdot min^{-1}$; MAU 0.23 ± 0.10 $g \cdot min^{-1}$, $p = 0.03$) and SIS (VOOM 0.32 ± 0.09 $g \cdot min^{-1}$; 0.23 ± 0.11 $g \cdot min^{-1}$, $p = 0.04$). Similarly, at 50 minutes, VOOM's carbohydrate oxidation rate per minute was significantly greater than MAU (VOOM 0.33 ± 0.17 $g \cdot min^{-1}$; MAU 0.19 ± 0.08

g·min^{-1}, p = 0.019) and SIS (VOOM 0.33 ± 0.17 g·min^{-1}; SIS 0.20 ± 0.07 g·min^{-1}, p = 0.03).

Furthermore, a significant main effect was found for time (p < 0.0001) and product (p = 0.03) on the rate of carbohydrate oxidation per 5-minute interval. VOOM demonstrated a greater rate of carbohydrate oxidation per 5-minute interval (2.07 ± 0.28 g·5-min^{-1}) compared to both MAU (1.68 ± 0.31 g·5-min^{-1}) and SIS (1.47 ± 0.38 g·5-min^{-1}). Tukey's multiple comparisons tests revealed that carbohydrate oxidation was significantly higher for VOOM than SIS between 15-20 minutes (VOOM 1.93 ± 1.09 g·5-min^{-1}; SIS 1.07 ± 0.69 g·5-min^{-1}; p = 0.03). At 50-55 minutes, carbohydrate oxidation was significantly greater for VOOM than both SIS (VOOM 2.27 ± 0.53 g·5-min^{-1}; SIS 1.96 ± 0.70 g·5-min^{-1}; p = 0.01) and MAU (VOOM 2.27 ± 0.53 g·5-min^{-1}; MAU 1.82 ± 0.91 g·5-min^{-1}; p = 0.008).

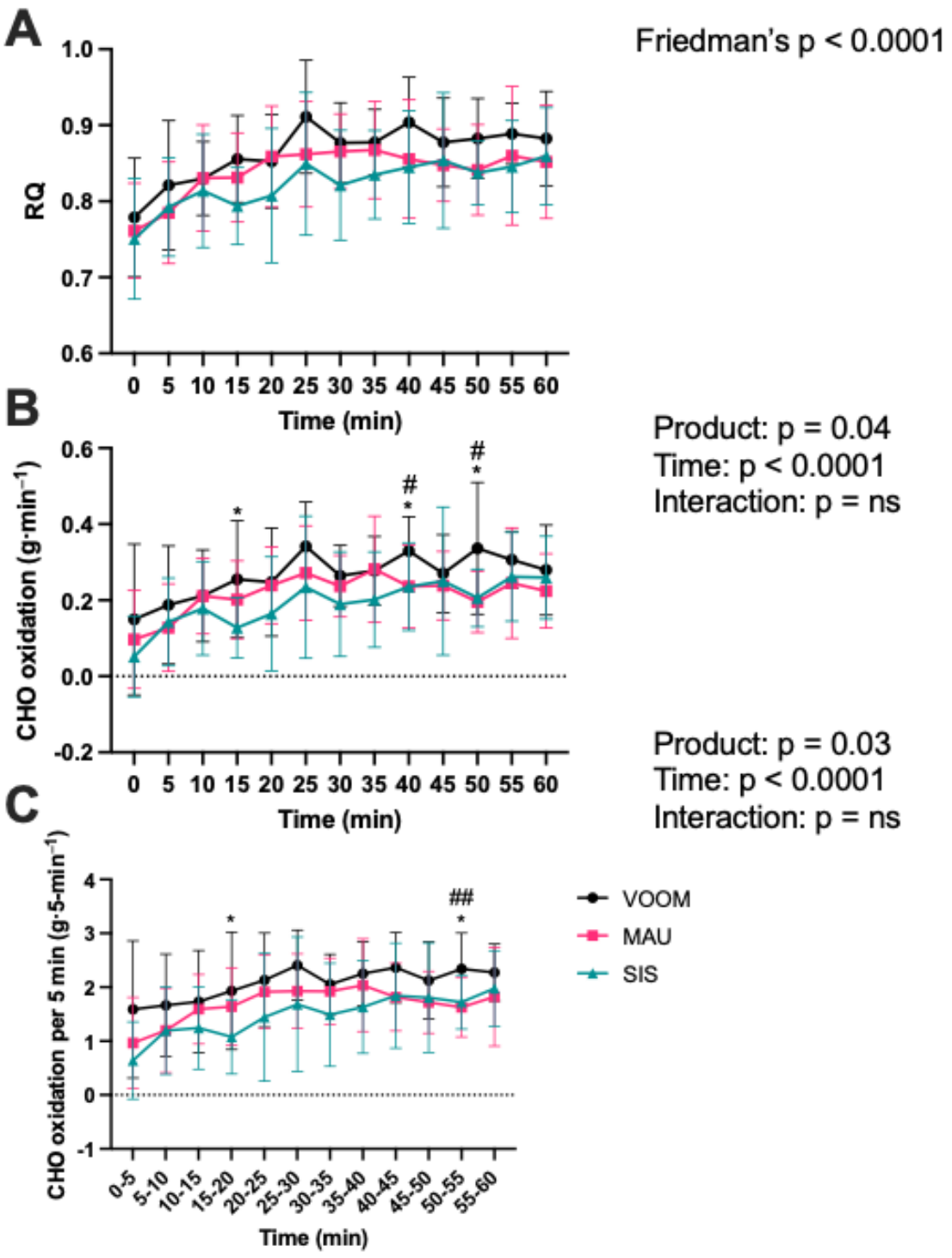

*Figure 9. (A) A higher RQ for VOOM than MAU and SIS, indicating increased CHO use. (B) VOOM has significantly greater CHO oxidation than SIS at 15 mins (p = 0.019) and greater than both MAU and SIS at 40 (p = 0.03, 0.04) and 50 mins (p = 0.019, 0.03). (C) Greater CHO oxidation for VOOM than SIS at 15-20 mins (p = 0.03) and greater than both MAU and SIS at 50-55 mins (p = 0.01, 0.008). * p < 0.05 for VOOM vs SIS, # p < 0.05, ## p < 0.01 for VOOM vs MAU. CHO = Carbohydrates.*

In keeping with the carbohydrate oxidation data, total fat oxidation significantly differed between products ($p = 0.007$). Total fat oxidation was suppressed to a greater extent for VOOM than SIS (SIS 9.45 ± 3.41 g, VOOM 7.37 ± 2.29 g, $p = 0.007$). No differences were observed between MAU and either VOOM or SIS (MAU 8.45 ± 3.36 g, $p > 0.05$).

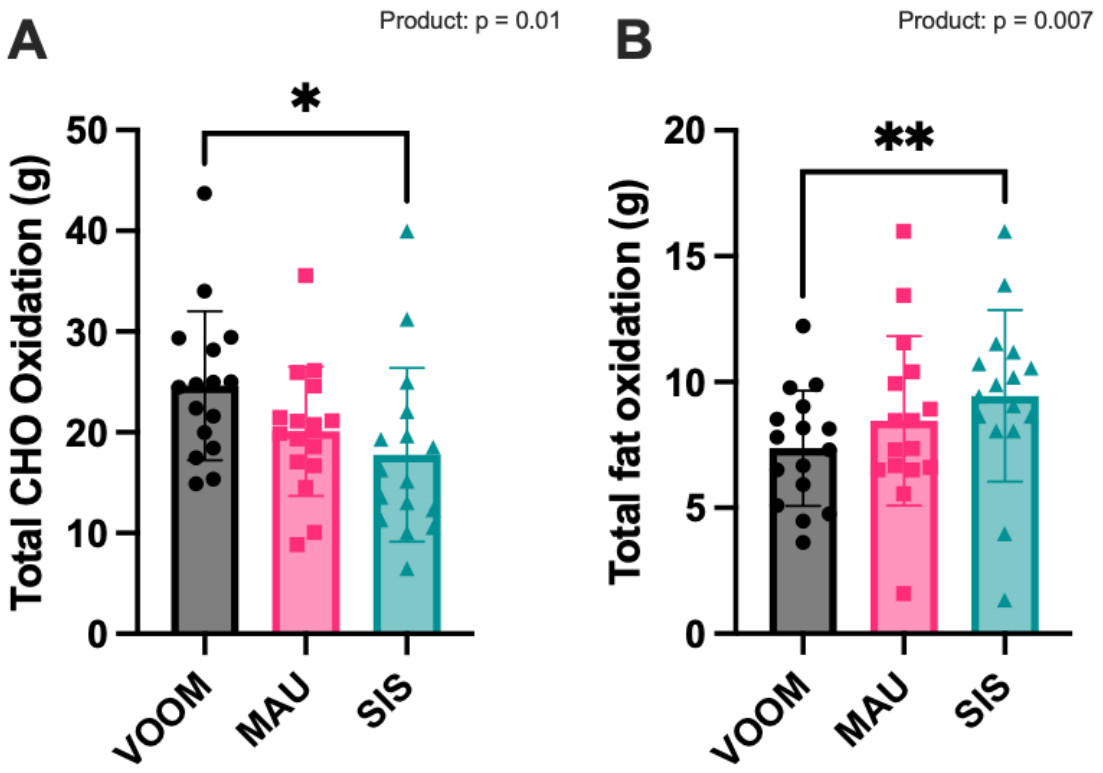

*Figure 10. (A) Consuming VOOM results in a significant increase in total CHO (carbohydrate) oxidation compared to SIS ($p = 0.01$), and (B) total fat oxidation was suppressed to a greater extent for VOOM than SIS ($p = 0.007$) during the 1-hour modified oral glucose tolerance trial. *$p < 0.05$; **$p < 0.01$.*

A two-way repeated measures ANOVA for fat oxidation per minute revealed a significant main effect for time ($p < 0.0001$) but not for product ($p = 0.18$). Fat oxidation per minute was again suppressed more in VOOM (0.08 ± 0.02 $g \cdot min^{-1}$) than MAU (0.09 ± 0.01 $g \cdot min^{-1}$) and SIS (0.10 ± 0.01 $g \cdot min^{-1}$). Tukey's post-hoc test revealed no significant differences between products at any time point ($p > 0.05$).

As data was non-normally distributed, a Friedman's test revealed significant differences in fat oxidation per 5-minute interval, X^2 (36) = 146.6, $p < 0.001$, with a greater mean rank for SIS (21) than MAU (19) and VOOM (14), indicating a higher fat oxidation rate per 5-minute interval for SIS. The raw data mean was again greater for SIS (0.78 ± 0.34 g·5-min^{-1}) than MAU (0.70 ± 0.35 g·5-min^{-1}) and VOOM (0.61 ± 0.26 g·5-min^{-1}). Dunn's multiple comparisons test again revealed no significant differences.

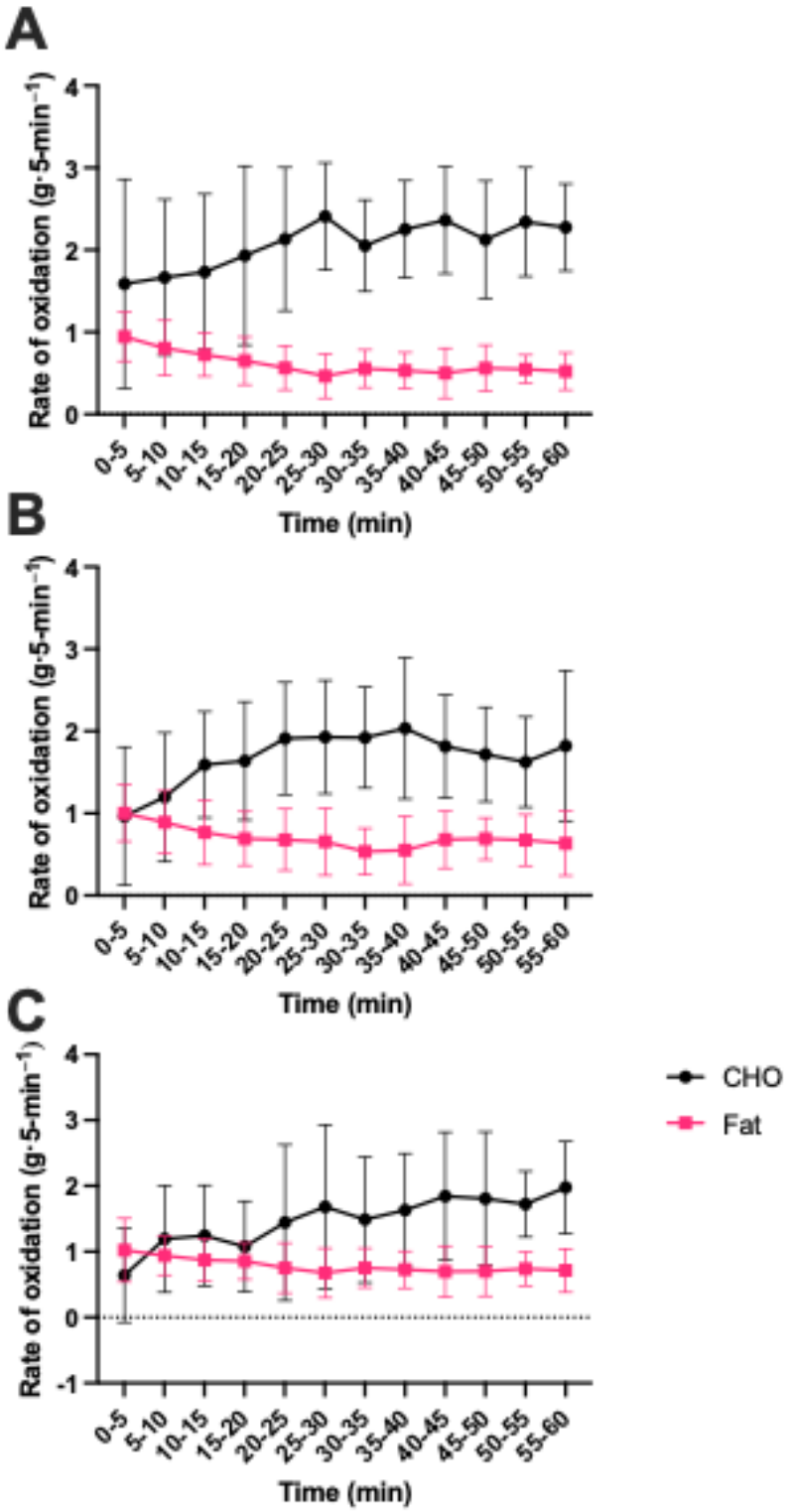

Figure 11. (A) VOOM elicits greater carbohydrate oxidation and suppresses fat oxidation per 5-minute interval to a greater extent than (B) MAU and (C) SIS, as shown by the greater gap between CHO and Fat oxidation for VOOM. CHO = Carbohydrate oxidation (g·5-min−1). Fat = Fat Oxidation (g·5-min−1).

2.6.4 VOOM elicits a greater lactate concentration

The blood lactate data were determined to be non-normally distributed, therefore a Friedman's test was performed. Blood lactate concentrations before supplement ingestion (baseline) did not differ significantly between study visits (VOOM 1.03 ± 0.56 mmol/L, MAU 0.66 ± 0.17 mmol/L, SIS 0.90 ± 0.62 mmol/L, p = 0.09). A Friedman's test revealed a significant difference in lactate concentration between the products (X^2 (41) = 253, p < 0.001), with mean ranks based on the relative position of each observation within its matched dataset. VOOM had a greater mean rank for lactate concentration (26) than MAU (20) and SIS (17). This was consistent with the raw mean data (VOOM 1.08 ± 0.42 mmol/L, MAU 0.91 ± 0.30 mmol/L, SIS 0.81 ± 0.31 mmol/L). Dunn's multiple comparisons revealed a significantly greater lactate concentration in VOOM than in SIS at 35 minutes (VOOM mean rank = 29, raw data mean = 1.17 ± 0.49 mmol/L, SIS mean rank = 14, raw data mean = 0.77 ± 0.28 mmol/L, p = 0.01), as shown in Figure 12.

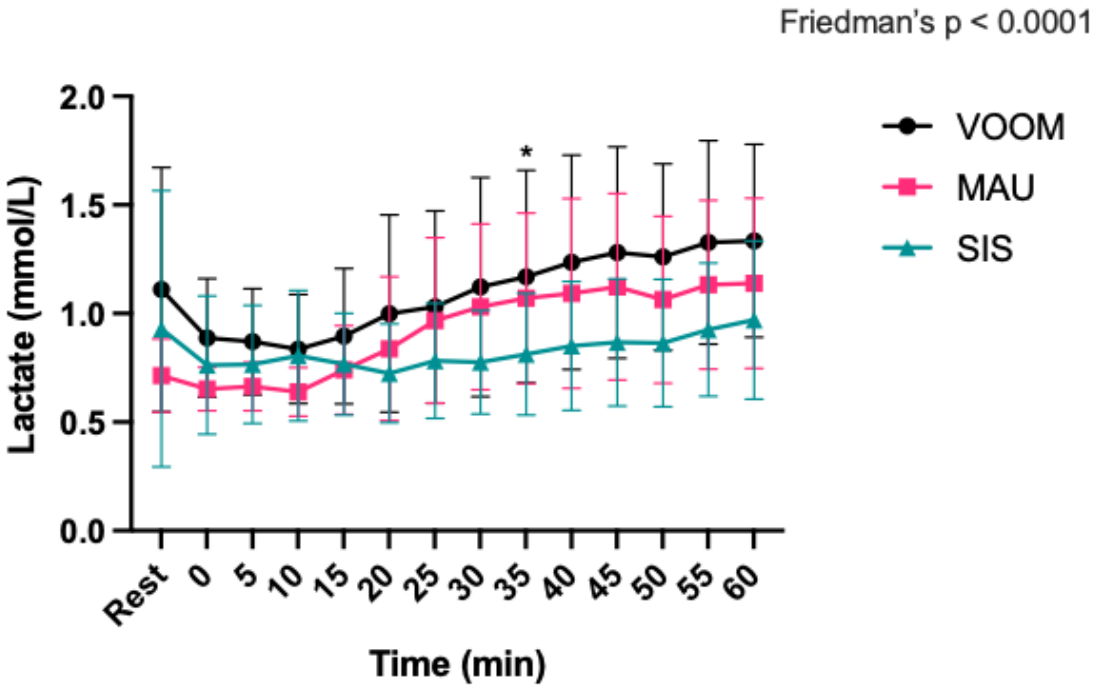

*Figure 12. Blood lactate was significantly greater for VOOM than SIS at 35 minutes (p = 0.01). *p < 0.05.*

There were no significant differences in the electrolyte content measured (sodium, potassium and chloride), with levels remaining similar throughout ($p > 0.05$).

Table 3. Mean electrolyte concentrations remained similar for all three products

Electrolyte levels	VOOM	MAU	SIS	p value
Na^+ (mmol/L)	141.2 ± 0.47	140.8 ± 0.45	140.9 ± 0.45	0.7
K^+ (mmol/L)	4.03 ± 0.08	4.04 ± 0.06	4.07 ± 0.05	0.4
Cl^- (mmol/L)	104.6 ± 0.32	104.7 ± 0.42	104.2 ± 0.4	0.6

Na^+ - Sodium, K^+ - Potassium, Cl^- - Chloride

2.7 Discussion

The findings of this study highlight the distinct metabolic responses elicited by VOOM, MAU and SIS during a one-hour modified oral glucose tolerance test. This study isolated the individual formulas of each product, which elicited significant differences in substrate utilisation. Notably, VOOM was shown to significantly enhance carbohydrate oxidation compared to MAU and SIS, suggesting a superior efficacy in promoting carbohydrate utilisation.

2.7.1 Substrate utilisation

The observed differences in carbohydrate oxidation highlight an enhanced carbohydrate utilisation with VOOM. VOOM demonstrated significantly greater total carbohydrate oxidation compared to SIS, with trends also suggesting it may outperform MAU, albeit not significantly. Furthermore, VOOM supplementation led to greater carbohydrate oxidation per minute and 5-minute intervals.

High carbohydrate oxidation is advantageous during endurance activities such as a mid-to-long-distance run (e.g., 10 km, marathon). By promoting elevated carbohydrate oxidation, VOOM provides readily available energy. This is crucial for individuals engaged in high-intensity or prolonged aerobic activities, reducing the reliance on slower energy systems like fat oxidation (Muscella et al., 2020). Moreover, efficient carbohydrate utilisation helps spare muscle glycogen,

delaying fatigue and enabling endurance athletes to maintain optimal performance for longer periods (Murray & Rosenbloom, 2018).

The greater carbohydrate utilisation observed with VOOM supplementation is further evidenced, with fat oxidation being suppressed to a greater extent for VOOM compared to MAU and SIS for total fat oxidation and lower fat oxidation per minute and 5-minute intervals. This reduction in fat utilisation suggests that, after consuming VOOM, subjects primarily relied on carbohydrate metabolism, reinforcing VOOM's superior carbohydrate utilisation, whereas consuming SIS may promote a greater reliance on fat oxidation.

Mean RQ was similar between products (VOOM 0.86 ± 0.06, MAU 0.84 ± 0.07, SIS 0.83 ± 0.07). An RQ closer to 1 indicates 100% carbohydrate oxidation, while a value of ≤ 0.7 indicates a reliance on fatty acid oxidation (Melzer, 2011).

Baseline insulin levels did not significantly differ between products, ensuring that the observed effects were due to the products consumed rather than pre-existing differences in insulin sensitivity caused by diet. Analysis of insulin concentrations revealed a significant effect of time on insulin levels, reflecting the expected response to carbohydrate intake. However, no significant product or interaction effects were found, suggesting comparable insulin responses between VOOM, MAU and SIS. Despite this, VOOM produced a greater area under the curve for insulin than MAU and SIS, indicating a more substantial or prolonged insulin response. This could be attributed to differences in carbohydrate composition or glycaemic index, though the absence of a product effect indicates that this observation did not reach statistical significance, potentially due to individual variability in insulin response.

Normalised data showed temporal patterns for glucose and insulin across all products, with no significant differences between them, reinforcing the comparable metabolic effects observed between VOOM, MAU and SIS.

2.7.2 Potential mechanisms underlying differences in substrate utilisation

VOOM may induce greater carbohydrate oxidation but comparable increases in blood glucose compared to MAU or SIS due to its combination of glucose and fructose. The VOOM bar's blend of glucose and fructose may allow for more efficient utilisation of carbohydrates, as glucose and fructose are metabolised via different pathways, leading to simultaneous absorption and higher overall carbohydrate oxidation (Ferraris & Diamond, 1997, Jentjens et al., 2004a). Because glucose and fructose do not compete for the same transporters or enzymes, they can be utilised simultaneously, leading to a higher total carbohydrate oxidation rate compared to products that primarily rely only on glucose (or glucose polymers), enhancing energy supply, particularly during prolonged exercise (Ferraris, 2001; Jeukendrup, 2010; Rosset et al., 2017).

Both the MAU and SIS carbohydrate delivery mechanisms differ. SIS utilises maltodextrin, which has been shown to provide effective energy delivery (Wallis et al., 2005). The SIS gels lower carbohydrate oxidation rate may be due to reliance primarily on maltodextrin, a glucose polymer, as its carbohydrate source. Maltodextrin, being a glucose polymer, requires enzymatic breakdown into glucose molecules before absorption, which can introduce a slight delay compared to free glucose, and, as glucose, is absorbed via SGLT1, which is suggested to have a limited absorption capacity of between 0.5 to 1 $g \cdot min^{-1}$ (Kellet, 2001; Jentjens et al. 2004a; Jentjens et al., 2004b; Jentjens et al., 2004c). VOOM's combination of glucose and fructose requires less initial enzymatic breakdown than maltodextrin, and the ability to use two distinct pathways allows for the simultaneous absorption of both carbohydrates which may increase the total carbohydrate oxidation rates, hence a greater oxidation rate than the maltodextrin-based SIS gel. In contrast to VOOM, the SIS gel is isotonic, meaning it has a similar concentration of dissolved particles as bodily fluids (Skarlovnik et al., 2024). This ensures it can be rapidly absorbed without the need for additional water to aid digestion. This characteristic may be advantageous during exercise, as reduced water intake is associated with lower reports of gastrointestinal discomfort (Zhang et al., 2015).

In comparison to both VOOM and SIS, MAU uses hydrogel technology to slow down the release of carbohydrates, with a fructose-glucose ratio of 0.8:1. Hydrogels, comprised of three-dimensional hydrophilic polymers containing sodium alginate and pectin, aid the absorption of multiple transportable carbohydrates by delivering them gradually at a pH level that is biocompatible to the stomach and intestine (King et al., 2020; Rowe et al., 2022). Hydrogel technology coats the glucose and fructose in a gel matrix, slowing gastric emptying and allowing for a more gradual and sustained release of energy. This slower carbohydrate release, and ultimately slower carbohydrate oxidation, helps to reduce gastrointestinal discomfort and ensures steady energy delivery, especially during prolonged endurance events. In contrast, VOOM's faster oxidation of carbohydrates, driven by its higher fructose content, is formulated to dissolve easily in the mouth, which may result in an immediate breakdown of energy compared to the more sustained release of the MAU hydrogel formulation.

2.7.3 Similar blood glucose concentrations

There were no significant changes in blood glucose concentration, peak glucose, or time to glucose peak, most likely due to all subjects consuming 45 grams of carbohydrates. Whilst not significant, VOOM reached its mean peak glucose concentration (mean peak glucose 6.59 ± 1.18 mmol/L, time to peak = 31.25 ± 13.96 min) quicker than both MAU (mean peak glucose = 6.20 ± 1.14 mmol/L, time to peak = 39.06 ± 12.28 min) and SIS (mean peak glucose = 6.42 ± 1.15 mmol/L, time to peak = 33.13 ± 11.09 min). This reflects the composition of the products, with MAU releasing energy at a more gradual speed due to its hydrogel formula than the faster-releasing formulas of VOOM (glucose-fructose) and SIS (maltodextrin).

2.7.4 Time to glucose peak and manufacture guidelines

It is not made explicitly clear by VOOM, MAU, or SIS when to consume their respective products before starting exercise. VOOM suggest consuming a segment of the bar (4x segments per bar) every 15-20 minutes during exercise

lasting upwards of 60-90 minutes. MAU provide no explicit information as to when the gel should be consumed but rather provides a guide dependent upon the type and duration of exercise. For example, the website suggests consuming one Maurten gel 160 1-4 hours before starting a 5-10 km run and again 15-45 minutes before a warm-up. SIS are again not explicit about when is best to consume the SIS Go Isotonic Energy Gel, suggesting a consumption of 1-3 gels per hour during exercise to deliver up to 60 g of carbohydrate.

Based solely on the findings of this resting study, it may be advised to consume VOOM 31.25 ± 13.96 min, MAU 39.06 ± 12.28 min, and SIS 33.13 ± 11.09 min before starting exercise, as this will ensure the products are reaching their peak glucose values as exercise begins, allowing for greater glucose availability for exercise.

While carbohydrate supplements such as those discussed in this research are so widely used due to their convenience and effective energy delivery, there is limited evidence identifying how long these supplements take to reach peak blood glucose levels, with the majority of the literature evaluating the effect these supplements have on exercise performance. Two studies have compared time to glucose peak at rest in carbohydrate energy supplements. Eckstein et al. (2021) provided healthy individuals with (i) 1 g/kg body mass (BM) glucose, (ii) 1 g/kg BM fructose, and (iii) 0.5 g/kg BM of glucose-fructose. Glucose reached peak blood glucose concentrations in 40 ± 13 min, fructose in 36 ± 22 min, and glucose-fructose in 29 ± 8 min, aligning with the results of this study for the glucose-fructose bar (VOOM), although this study did not find a significant difference in time to glucose peak with the products compared. Johansen et al. (2024) compared maltodextrin to other carbohydrates and found that the time to-glucose peak for maltodextrin was 38 ± 11 min. This is not too dissimilar to the time to glucose peak observed for the maltodextrin-based gel (SIS) tested in this study. These findings suggest that maltodextrin has a relatively slower time to glucose peak, which is in contrast to the faster peak times typically seen with glucose-fructose combinations. However, due to the different dosing and compositions, direct comparisons between maltodextrin and glucose-fructose peak times should be made cautiously.

Individual differences among subjects were a significant source of variability in the data. This variance may have led to an increase in non-normally distributed data. To accommodate for non-normally distributed data, a series of Friedman's tests revealed significant main effects among the products for multiple metabolic measures, including RQ, fat oxidation per 5-minute interval, lactate, and electrolyte concentration. Certain products consistently demonstrated both greater mean ranks and raw data means in these measures. However, Dunn's post hoc pairwise comparisons, adjusted using Bonferroni corrections to account for multiple comparisons, did not identify significant differences between the products for most variables. This may emphasise the role of individual variability within the data, despite observable trends.

This highlights that individual responses to energy supplements vary and suggests the importance of personalised nutrition strategies, as previously outlined by Jeukendrup (2014), who identified several factors that may impact individual response to carbohydrate absorption. Jeukendrup (2014) suggested individuals who consume higher doses of carbohydrates more regularly may have an increased capacity to absorb them, essentially training the gut to cope with different quantities and types of carbohydrates. The level of daily carbohydrate consumption was not recorded in the present study, so inferences cannot be made regarding how well-adapted subjects were to carbohydrate supplements. However, subjects were matched for the level of competition (Tier 2 runners, cyclists and triathletes) and body mass index (BMI between 18.5 and 24.9 kg/m^2), so factors such as training status and body mass should not greatly impact these results. Breakfast meals were recorded on the day of the first visit and subjects were asked to replicate this, minimising the effect of diet on study findings.

2.8 Limitations

While every effort was made to ensure the researcher remained blinded to which supplement was taken in each trial, subjects were naturally aware that one of the supplements was a bar while the others were gels. This difference in physical

form may have influenced the blinding process despite measures taken to minimise bias. However, due to subjects not being aware of the product names or specific details, the blinding process was maintained to a degree unlikely to have significantly affected the study findings.

A limitation of this study is the use of antegrade venous cannulation. The ‘gold-standard’ technique for obtaining "arterialised" venous blood involves the insertion of a retrograde venous cannula and heating the hand above 37°C to mimic arterial blood characteristics without invasive arterial cannulation (Hengist et al., 2017). While retrograde venous cannulation offers a less invasive alternative for measuring metabolites and hormones than measuring directly from an artery, it is technically challenging and causes more discomfort than antegrade methods. A recent review found minimal differences in metabolite measurements between the two techniques and noted that retrograde methods increase failure rates and discomfort without improving reproducibility (Wrench et al., 2024).

Breath-by-breath gas exchange was measured using a face mask, which can produce more variable data than a canopy hood typically used in resting studies. Canopy hoods achieve a steady state more easily and are often more comfortable for participants. However, studies show little difference in accuracy between face masks and canopy hoods for indirect calorimetry (Segal, 1987; Isbell et al., 1991; Forse et al., 1993; Bauer et al., 1997). A face mask was used in this study due to mechanical issues with the canopy hood, but future studies may opt for the latter to reduce ventilation variability (Wang et al., 2017).

One of the main limitations of this study, reducing the generalisability of its findings, was the male-only inclusion criteria. Females are significantly underrepresented in medical and sports science research (D'Lauro et al., 2022; Mayor et al., 2022). Historically, research conducted on males has been assumed to apply to females without accounting for biological sex differences, posing ethical issues and risks such as misdiagnosis, incorrect treatment, injury, and suboptimal performance outcomes for females in sports science.

While the researchers acknowledge the ethical concerns of studying just one sex of participants, the male-only criteria were chosen due to time and funding constraints. As part of a 1-year educational project with limited funding, including females would have required a larger sample size, increasing costs and time. Additionally, the female menstrual cycle and hormonal differences affect glucose uptake and insulin sensitivity. Oestrogen, dominant in the follicular phase, enhances insulin sensitivity, while progesterone, dominant in the luteal phase, reduces it – causing variability in glucose regulation, particularly in females with type 1 diabetes (Barata et al., 2013; Mauvais-Jarvis et al., 2013; Varlamov et al., 2015; Gamarra & Trimboli, 2023).

Accounting for these differences would require controlling for menstrual phases and contraception methods, complicating recruitment and extending the study's timeline. Future research should include females to compare findings with this male-only cohort, providing insights into sex-based differences in energy supplement consumption, glucose uptake, and insulin regulation.

2.9 Conclusion

These results suggest that the VOOM glucose-fructose bar delivers carbohydrates as quickly, or perhaps even quicker, than a fructose-glucose hydrogel (MAU) or a maltodextrin-based energy gel (SIS), providing athletes with an effective alternative for carbohydrate supplementation.

3. CHAPTER 3: No differential effects of a glucose-fructose energy bar, a fructose-glucose hydrogel, and a maltodextrin-based energy gel on repeated sprint performance

3.1 Abstract

This study investigated the effect of three carbohydrate products on repeated maximal sprint performance in a double-blind, randomised design: a glucose-fructose energy bar (Voom Pocket Rocket; VOOM), a fructose-glucose hydrogel (Maurten Gel 160; MAU), and a maltodextrin-based gel (SIS Go Isotonic; SIS). Ten healthy Tier 2 runners (aged 25 ± 4.7 years; height 176.3 ± 7.6 cm; weight 74.3 ± 10.3 kg; BMI 23.2 ± 10.3 kg/m²) completed five 15-second maximal sprints on a cycle ergometer against 0.075 kg · kg-1 body mass, with 3-minute active recovery intervals. Subjects ingested 45 g of carbohydrates from either VOOM, MAU, or SIS across three study visits. Blood samples were collected 35 minutes after ingestion and again after each sprint and recovery period to measure glucose, lactate, and electrolytes (sodium, potassium, chloride, calcium). Substrate utilisation was measured using indirect calorimetry. Peak power, mean power, total work, and fatigue index were recorded. Subjects also reported ratings of perceived exertion (RPE) and gastrointestinal discomfort. Glucose and lactate concentrations varied over time ($p < 0.0001$) but did not differ between products ($p > 0.05$). Potassium and chloride levels also changed over time ($p = 0.001$ and $p = 0.02$, respectively) without product-specific effects ($p > 0.05$). No significant changes were observed for sodium or calcium ($p > 0.05$). Peak power, mean power, and total work fluctuated over time ($p < 0.01$) but were not influenced by the type of product ($p > 0.05$). Changes in RPE and gastrointestinal discomfort were similar across all products ($p > 0.05$). VOOM, MAU, and SIS produced comparable metabolic and performance outcomes, indicating that the type of carbohydrate supplement does not significantly affect sprint performance or metabolic responses.

3.2 Introduction

Carbohydrate supplements are critical for sustaining energy during intermittent and high-intensity events, such as during the final stages of a cycling race, or repeated sprints during team sports like football. In these bursts of explosive effort, quick and efficient energy delivery becomes crucial. Sprinting relies heavily on glycogen stores, the body's primary energy source for anaerobic activity (Vigh-Larsen et al., 2021; Vigh-Larsen et al., 2022a; Vigh-Larsen et al., 2022b). During maximal sprints, the body's demand for adenosine triphosphate (ATP) is extremely high due to the intense muscle contractions needed to power the exercise. Sprinting recruits nearly all motor units in the muscles being used, which requires a large amount of energy to power the cross-bridge cycling of actin and myosin, the proteins responsible for muscle contraction (Geeves et al., 2005; Fitts, 2008; Galvan-Alvarez et al., 2024). ATP is required for both the power stroke (muscle contraction) and the release of the myosin head from actin (muscle relaxation). This leads to a rapid turnover of ATP, known as the Sliding Filament Theory (Huxley, 1957; Huxley & Simmons, 1971; Huxley & Kress, 1985). Maximal sprints also primarily utilise fast twitch muscle fibres (Type II) as these are specialised for high-intensity and explosive movements and rely heavily on anaerobic metabolism, which depends on phosphocreatine (PCr) and glycogen for rapid ATP resynthesis (Greenhaff et al., 1994; Martin-Rodriguez et al., 2024). The body cannot deliver oxygen quickly enough to sustain ATP production during a maximal sprint. Therefore, it relies on the phosphagen system, which uses stored ATP and PCr, and anaerobic glycolysis, which uses glycogen stores.

Intramuscular PCr stores are used for rapid high-intensity contractions but are almost fully depleted in under 30 seconds and are not fully replenished until after a few minutes of recovery (Spencer et al., 2005). PCr donates a phosphate group to adenosine diphosphate (ADP), rapidly regenerating ATP, catalysed by the enzyme creatine kinase (Baker et al., 2010; Archacki et al., 2024). Once these PCr stores are depleted, blood glucose and muscle glycogen can be broken down rapidly through anaerobic glycolysis to generate ATP (Baker et al., 2010; Archacki et al., 2024).

During glycolysis under aerobic conditions, one molecule of glucose breaks down to form two molecules of pyruvate and two molecules of ATP. Pyruvate then enters the mitochondria, where it is converted into acetyl-CoA by pyruvate dehydrogenase. Acetyl-CoA then enters the tricarboxylic cycle, leading to the production of more ATP and the electron transporters nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide ($FADH_2$), which are used in the electron transport chain for oxidative phosphorylation, leading to 30-32 molecules of ATP (Chaudhry & Varacallo., 2018; Melkonian & Schury., 2019).

When there is a lack of oxygen, such as during maximal sprinting efforts, pyruvate does not enter the mitochondria. Instead, pyruvate is converted to lactate via lactate dehydrogenase, which regenerates NAD+ to sustain glycolysis (Baker et al., 2010; Melkonian & Schury, 2019). Anaerobic glycolysis produces two ATP per glucose molecule. Whilst less efficient than aerobic glycolysis, anaerobic glycolysis is significantly quicker, allowing the fuelling of maximal and repeated sprints (Archacki et al., 2024; Tortu et al., 2024). To sustain this process, glycogenolysis rapidly breaks down glycogen into glucose-1-phosphate via glycogen phosphorylase, which is then converted to glucose-6-phosphate and enters glycolysis (Vigh-Larsen et al., 2021). This process is stimulated by increased calcium levels and adrenaline during intense exercise, ensuring a quick supply of glucose when energy demand is high (Febbraio et al., 1998; Kjaer et al., 2000). In anaerobic conditions, glucose-6-phosphate is metabolised through glycolysis to produce ATP, with pyruvate being converted to lactate to sustain energy production. Glycogenolysis is crucial for maintaining performance during maximal and repeated sprint efforts.

The metabolic effects of repeated-sprint efforts differ slightly from single maximal sprints due to the greater involvement of aerobic metabolism. Research suggests anaerobic energy production declines with successive sprints, but total work output can be maintained due to increased oxygen uptake during recovery periods (Spencer et al., 2005; Ulupinar et al., 2023). Sprint duration, number of bouts, and recovery time all significantly influence the contribution of individual energy systems (Ulupinar et al., 2023; Thurlow et al., 2024; Thurlow et al., 2025).

ATP depletion during repeated sprints varies, with more intense exercise and reduced recovery time leading to greater declines in ATP. PCr resynthesis plays a vital role in maintaining repeated sprint performance, but short recovery periods, such as in team sports, may limit full PCr resynthesis and thus limit power output during subsequent sprints (Mendez-Villanueva et al., 2012). However, this is debated, with some research indicating that neither the type of recovery (active vs passive) nor its duration (short vs long) significantly affects PCr resynthesis rates or subsequent performance (Germano et al., 2022; Zouhal et al., 2024).

The reliance on anaerobic glycolysis decreases across repeated sprints due to lower glycogen availability, reducing glycolytic rates and ultimately impairing sprint performance. As a result, ATP production increasingly shifts towards oxidative metabolism (Vigh-Larsen et al., 2021). Research has consistently shown intermittent high-intensity exercise depletes glycogen stores (Kuipers et al. 1987; Wallis et al. 2008; and Podlogar et al. 2023). A common glycogen depletion protocol used in these studies consists of repeated 2-minute cycling bouts at 90% maximal workload (W_{max}), interspersed with 2 minutes at 50% W_{max}, before progressively decreasing to 80% and then 70% W_{max} until the athlete can no longer sustain 2-minute bouts at 70% W_{max}. Studies in team sports like football further demonstrate that glycogen depletion impairs performance, specifically, the ability to perform repeated sprints, emphasising the need for effective glycogen management strategies (Mohr et al., 2022; Mohr et al., 2023; Kazemi et al., 2023).

To prevent glycogen stores from being depleted during high-intensity and intermittent exercise, an effective fuelling strategy is essential. To evidence this, a glycogen depletion protocol combined with a low carbohydrate intake before a 1500 metre time trial resulted in a 4.5-second performance decrease compared to a higher carbohydrate intake, highlighting the importance of pre-exercise carbohydrate consumption (Venckunas et al., 2024).

In addition to a high-carbohydrate diet, athletes can consume carbohydrate-rich energy supplements before intense exercise to elevate blood glucose levels, a strategy commonly referred to as ‘carbohydrate loading’ (Baker et al., 2015; Kazemi et al., 2023; Ismardi et al., 2024). While muscle glycogen remains the primary fuel source during maximal sprints due to anaerobic glycolysis, elevated blood glucose levels from energy supplements may further support recovery by fuelling the aerobic system. This may help preserve glycogen stores for subsequent sprints and prevent hypoglycaemia, potentially sustaining performance during exercise.

This is evidenced by Krings et al. (2017), who compared the influence of carbohydrate ingestion and carbohydrate mouth rinse during repeated maximal cycling sprints. Fatigue index, a measure used to quantify the decline in performance during repeated efforts, was attenuated with carbohydrate ingestion (15.3 ± 8.6 watts/s) compared to mouth rinse (17.7 ± 10.4 watts/s). Mean power output and total work (659.3 ± 103.0 watts, 9849.8 ± 1598.8 joules) were also greater with carbohydrate ingestion than with mouth rinse (645.8 ± 99.7 watts, 9447.5 ± 1684.9 joules). Similarly, Cooper et al. (2014) found a carbohydrate gel attenuated fatigue index (mean 5.0 ± 1.7) compared with a placebo (mean 7.4 ± 2.4).

This study compared how popular carbohydrate energy supplements affect repeated sprint performance. This study will translate how the speed of glucose absorption and substrate utilisation impacts exercise performance, specifically repeated sprint cycling performance, and whether consuming carbohydrate energy supplements maintains performance during exercise. This study used similar methods and subjects to the first study included in this thesis, but the inclusion criteria were adapted to ease recruitment.

3.3 Aims

This study aimed to evaluate the effect of three commercially available carbohydrate supplements on repeated maximal sprint performance in a double-blind, randomised crossover design.

3.4 Methods

3.4.1 Subject recruitment

Subjects were recruited through local sports clubs, social media, and posters, contacted to discuss the study and eligibility criteria, and, if deemed suitable, provided with an information sheet and an in-person screening date.

3.4.2 Subjects

A sample of ten Tier 2 (McKay et al., 2021) male and female runners, aged 18-40 years old, were recruited from local and University sports clubs and gave written informed consent to take part. The risks, benefits and requirements for each study visit were outlined to all subjects, and they had an opportunity to ask questions before providing written informed consent. This was a registered clinical trial (NCT06768333) that received ethical approval from Lancaster University Medical School (ethics number: LMS-24-Dean-2) and was conducted in the Human Performance Laboratory at Lancaster University. All testing was done in accordance with the Declaration of Helsinki and Good Clinical Practice. Subject characteristics are detailed in Table 4.

Table 4. Subject demographics (mean ± SD)

	Males (5 runners)	Females (5 runners)	Total (10 runners)
Age (years)	27.8 ± 5.7	23.2 ± 1.8	25.5 ± 4.7
Height (cm)	181.9 ± 3.4	170.7 ± 6.2	176.3 ± 7.6
Weight (kg)	80.4 ± 7.8	68.1 ± 8.9	74.3 ± 10.3
BMI (kg/m^2)	23.8 ± 1.3	22.7 ± 2.1	23.2 ± 10.3
Lean mass (kg)	65.6 ± 3.9	48.3 ± 3.1	56.9 ± 9.7
Body fat (%)	13.7 ± 3.5	24.6 ± 5.7	19.2 ± 7.3

BMI – Body Mass Index

3.4.3 Medical screening

Subjects included healthy males and females aged 18-40 years, classified as Tier 2 runners (McKay et al., 2021), with a Body Mass Index (BMI) of 18.5–24.9 kg/m² based on NHS-defined healthy ranges and prior research on athletes' BMI (Knechtle et al., 2011; Marc et al., 2014; Heller et al., 2022; NHS, 2022). Subjects attended the Human Performance Laboratory at Lancaster University and completed a medical screening form aligned to the American College of Sports Medicine (ACSM) safety to exercise guidelines (Liguori, 2020) to confirm no contraindications or allergies to study supplements (See Appendix). Blood pressure was also taken using an automatic blood pressure monitor (M3 Comfort, Omron, Kyoto, Japan) to ensure subjects were safe to exercise. Subjects were excluded if they had any medical conditions, took medications, or adhered to diets affecting gut microbiome glucose responses, including high-carbohydrate-low-fat (HCLF), low-carbohydrate-high-fat (LCHF), and ketogenic and glycogen manipulation diets (Rauch et al., 2022). Subjects refrained from caffeine, drugs, alcohol, and strenuous exercise for 24 hours before screening and study visits. Height and body mass were measured using an ultrasonic stadiometer and scales (217 ultrasonic stadiometer and scales, Seca, Hamburg, Germany), while body composition was assessed with a Tanita DC-430P (Tanita, Tokyo, Japan).

Female participants reported their contraceptive use. Hormonal contraceptives stabilise menstrual cycle fluctuations, resulting in more consistent metabolic and performance responses compared to naturally menstruating females, whose glucose, insulin, and lactate levels vary cyclically. For non-contraceptive users, the menstrual cycle stage was recorded, and subsequent visits were matched to account for hormonal fluctuations. This improves accuracy when comparing groups, as contraceptive use reduces variability and aligns female responses more closely with the hormonal consistency observed in males, enhancing comparability in exercise and nutrition research (Elliott-Sale et al., 2020).

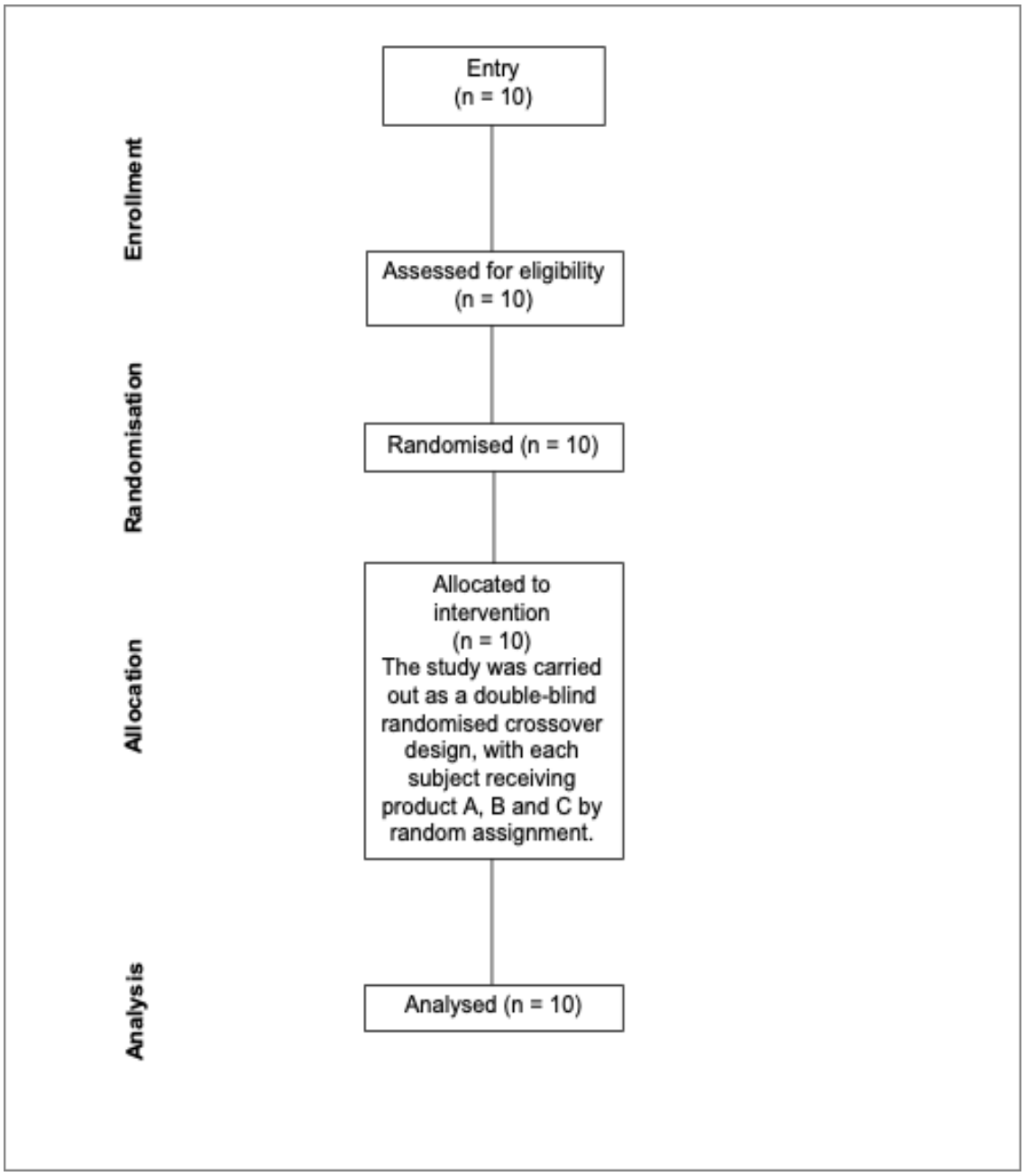

Figure 13. CONSORT flow chart and study design. A double-blind randomised crossover design.

3.4.4 Control snack

Subjects consumed two snack bars containing 11% fat, 10% carbohydrate, and 7% protein (Nature Valley Oats and Honey Crunchy Bars) two hours before arrival at the Human Performance Laboratory. After consuming the snack bar, subjects were required to fast for two hours but could drink water ad libitum.

3.4.5 Supplement administration

The supplements compared in this study were the Voom Pocket Rocket Electro Energy Bar (VOOM), Maurten Gel 160 (MAU), and Sport in Science Go Isotonic Energy Gel (SIS). Nutritional information can be seen in Table 5. Supplement administration was conducted in a double-blind and randomised manner. Each supplement was carefully matched to provide 45 g of carbohydrates. All supplements were prepared by a laboratory technician certified in Food Hygiene. Supplements were prepared and randomised by the laboratory technician using an online randomisation tool (Research Randomiser: https://www.randomizer.org). Neither the participants nor the researchers involved in data collection and analysis knew which supplements were being consumed. The laboratory technician was not involved in analysing the data, maintaining blinding throughout the study. The supplements were provided to the subjects 35 minutes before testing began by a laboratory technician in clear plastic bowls. This time was chosen based on the mean average results of the first study included in this thesis, which found time to glucose peak was 31.25 ± 13.96 minutes for VOOM, 39.06 ± 12.28 minutes for MAU, and 33.13 ± 11.09 minutes for SIS. The laboratory technician weighed the supplements before and after consumption to ensure all 45 g of carbohydrates had been consumed (this equates to 47 g of VOOM, 73.125 g of MAU, and 122.7 g of SIS). Subjects consumed 48.4 ± 1.78 g of VOOM, 75.22 ± 1.55 g of MAU, and 122.3 ± 1.49 g of SIS.

Table 5. Nutritional information of energy supplements consumed

Supplement	Ingredients	Nutritional information (matched for 45 g carbohydrate)
VOOM	Raw Cane Sugar, Glucose Syrup, Water, Dried Fruit (1%), Electrolytes (Tri-sodium Citrate, Pink Himalayan Salt, Potassium Chloride, Magnesium Oxide, Calcium Lactate) (0.3%), Natural Flavouring, B-Vitamins. No artificial sweeteners, thickeners or preservatives	176 kcal, 45 g carbohydrates, 41 g of which sugar, 0 g fat, 0 g protein, trace salt, 1 mg B-Vitamins, 120 mg electrolytes
MAU	Water, glucose, fructose, gelling agent: calcium carbonate, gelling agent: gluconic acid, gelling agent: sodium alginate	180 kcal, 45 g carbohydrates, 45 g of which sugars, 0 g fat, 0 g protein, 90 mg salt
SIS	Water, Maltodextrin (from Maize) (33%), Gelling Agents (Gellan Gum, Xanthan Gum), Natural Flavouring, Acidity Regulators (Citric Acid, Sodium Citrate), Preservatives (Sodium Benzoate, Potassium Sorbate), Sweetener (Acesulfame K), Sodium Chloride, Antioxidant (Ascorbic Acid)	178 kcal, 45 g carbohydrates, 1.23 g of which sugars, 0 g fat, 0 g protein, 20 mg salt

3.4.6 Experimental visits

Subjects were required to complete three separate experimental visits separated by at least 48 hours. This was to replicate the frequency of Tier 2 athletes' training. Subjects arrived at the Human Performance Laboratory after consuming the control snack and a 2-hour fast. Subjects were required to refrain from strenuous physical activity, caffeine, and alcohol for 24 hours prior. Subjects were asked to record their breakfast meal from the day of the first experimental visit and were asked to replicate this for each of the following two visits. Each experimental visit was scheduled for the same time of day ± 1 hour 40 minutes, and the temperature of the Human Performance Laboratory was set to 20°C. Upon arrival at the Human Performance Laboratory, subjects had their height and body mass measured (217 ultrasonic stadiometer and scales, Seca, Hamburg, Germany). Then, an antegrade venous cannula (Vasofix Safety IV Catheter 18G, BBraun, Sheffield, UK) was inserted into a superficial vein in the antecubital fossa by a member of the research team qualified in this procedure. Once secured in place, a needle-free valve (Bionector, JAK, York, UK) was inserted into the end of the cannula. Subjects were then required to consume one of the three supplements at random. To standardise, subjects had 2 minutes to fully consume the supplement. Once subjects had fully consumed the supplement, a timer was set to 35 minutes. During this time, subjects were adjusted to the exercise bike (Monark 894E static cycle ergometer, Monark, Vansbro, Sweden), ensuring proper saddle height, handlebar position, and pedal alignment, and a heart rate monitor was fitted to their chest (Polar H10, Polar, Kempele, Finland).

3.4.7 Repeated sprint protocol

The exercise protocol used in this study is an adaptation of Krings et al. (2017), who investigated the effects of carbohydrate ingestion on repeated sprint performance. First, a Hans Rudolph face mask was fitted (Hans Rudolph 7450, Hans Rudolph, Kansas, USA). This was connected to an online gas analyser (Cortex Metalyzer 28-R3, Cortex, Leipzig, Germany) to measure substrate utilisation via indirect calorimetry, recording the respiratory exchange ratio (RER) and calculating carbohydrate oxidation rate via the volume of oxygen ($\dot{V}O_2$) and carbon dioxide ($\dot{V}CO_2$).

Following a 3-minute warm-up of cycling at 70 revolutions per minute (rpm), subjects were required to perform a total of five 15-second maximal sprints on a cycle ergometer against 0.075 kg · kg^{-1} body mass (15-second Wingate Anaerobic Test), each separated by 3 minutes of active recovery cycling at 70 rpm against no resistance. This was followed by a cool-down until the subject felt comfortable enough to stop exercising.

3.4.8 Calculations

Peak power, mean power output, fatigue index and total work were recorded as performance metrics. Fatigue Index (%) was calculated using the following calculation:

([Peak Power – Minimum Power]/Peak Power) × 100

Subjects also completed a modified version of the Gastrointestinal Symptom Rating Scale (Svedlund et al., 1988) and Borg's (1982) 6-20 rating of perceived exertion before and after completing the exercise protocol (See Appendix).

3.4.9 Substrate utilisation

Carbohydrate oxidation ($g \cdot min^{-1}$) was calculated from the volume of oxygen ($\dot{V}O_2$) and carbon dioxide ($\dot{V}CO_2$) using the stoichiometric equations described by Jeukendrup & Wallis (2005). These equations were chosen as they are commonly used to calculate carbohydrate oxidation rates within exercise studies accounting for dynamic changes in substrate oxidation and higher RER values during varying exercise intensities, with protein oxidation considered negligible. The author did not include fat oxidation data as it is well known the body relies on carbohydrate metabolism as a fuel source during sprinting above 85% VO_2 max (Spriet., 2014). The Jeukendrup & Wallis (2005) equations used were:

Carbohydrate oxidation ($g \cdot min^{-1}$) = 4.210 x $\dot{V}CO_2$ (L/min) – 2.962 x $\dot{V}O_2$ (L/min)

3.4.10 Blood sampling and analysis

Baseline blood samples (1 ml) for glucose, lactate and electrolytes were taken 35 minutes after consumption of the supplement. Blood samples were then taken after every stage of cycling, starting after the 3-minute warmup and repeated immediately after each 15-second maximal sprint and 3-minute period of active recovery. The blood was sampled using a 1 ml syringe before being ejected onto a non-absorbent pad. Ten microliters (µL) were collected in a capillary tube to be analysed for glucose and lactate using a benchtop blood analyser (Biosen C-Line GP+, EKF, Barleben, Germany). Sixty µL was collected to analyse electrolyte concentration (sodium, potassium, chloride, calcium) using an electrolyte analyser (i-smart 30 PRO, Woodley Laboratory Diagnostics, Bolton, United Kingdom). A schematic of the study design can be seen in Figure 14.

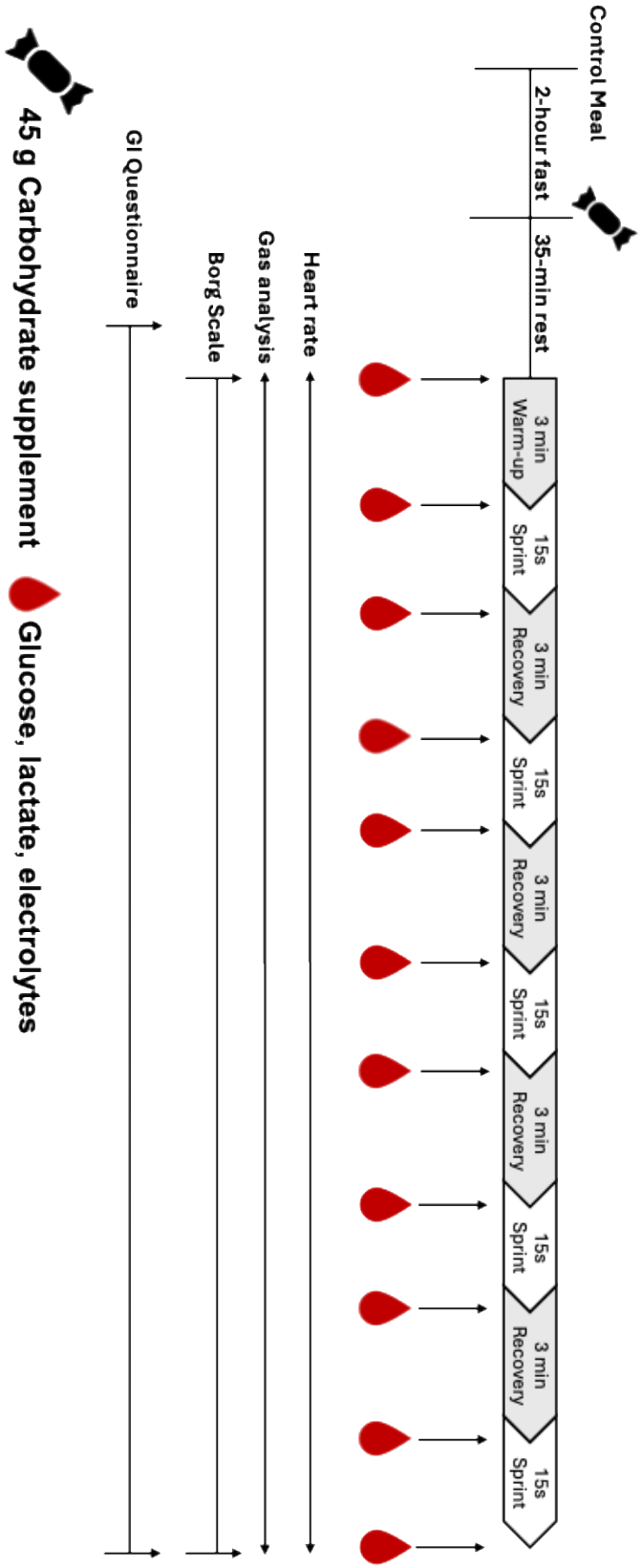

Figure 14. Schematic of the study design

3.5 Statistical analysis

Data were tested for normality using Shapiro-Wilk tests. The mean and standard deviation (SD) are reported unless otherwise stated. Time-series data for normally distributed variables were analysed using repeated measures ANOVA with product and time as within-subject factors. Where there was a significant main effect for treatment (Product), time, or interaction, the location of differences was further probed using the Tukey post-hoc test. Non-normally distributed variables were analysed using Friedman's test. Where there was a significant main effect for treatment (Product), time, or interaction, the location of differences was further probed using Dunn's post-hoc comparison tests. Both were corrected using Bonferroni adjustments to account for multiple comparisons. Data analysis and figure preparation were conducted using GraphPad Prism 10.4.1 (GraphPad Software, San Diego, CA, USA). Significance was defined as $p < 0.05$.

3.6 Results

3.6.1 Sex differences in sprint cycling

A two-way repeated measures ANOVA revealed a significant effect of sex on mean peak power ($p < 0.0001$). Tukey's multiple comparisons test revealed a significant difference in mean peak power between males and females for VOOM (males 861.4 ± 97.45 W; females 612 ± 94.47 W, $p = 0.01$), MAU (males 826.8 ± 93.79 W; females 601.9 ± 94.30 W $p = 0.02$) and SIS (males 856.7 ± 101.3 W; females 599.5 ± 104.9 W, $p = 0.01$). Similarly, a significant effect of sex on mean power was revealed ($p < 0.0001$). Tukey's multiple comparisons test revealed a significant difference in mean power between males and females for VOOM (males 684.7 ± 65.96 W; females 501.4 ± 53.97 W, $p = 0.01$), MAU (males 668.4 ± 66.83 W; females 518.9 ± 51.28 W $p = 0.04$) and SIS (males 691.5 ± 67.97 W; females 487.3 ± 63.58 W, $p = 0.006$). Furthermore, a significant effect of sex was revealed for the mean total work completed ($p < 0.0001$). Tukey's multiple comparisons test revealed a significant difference in total work between males and females for VOOM (males 10131 ± 982.4 kJ; females 7365 ± 838.4 kJ, $p =$

0.01), MAU (males 10047 ± 1096 kJ; females 7559 ± 708.2 kJ, p = 0.02), and SIS (males 10231 ± 1096 kJ; females (7208 ± 927.2 kJ, p = 0.007). No significant effect of sex was found for the fatigue index (p = 0.2), as shown in Figure 15.

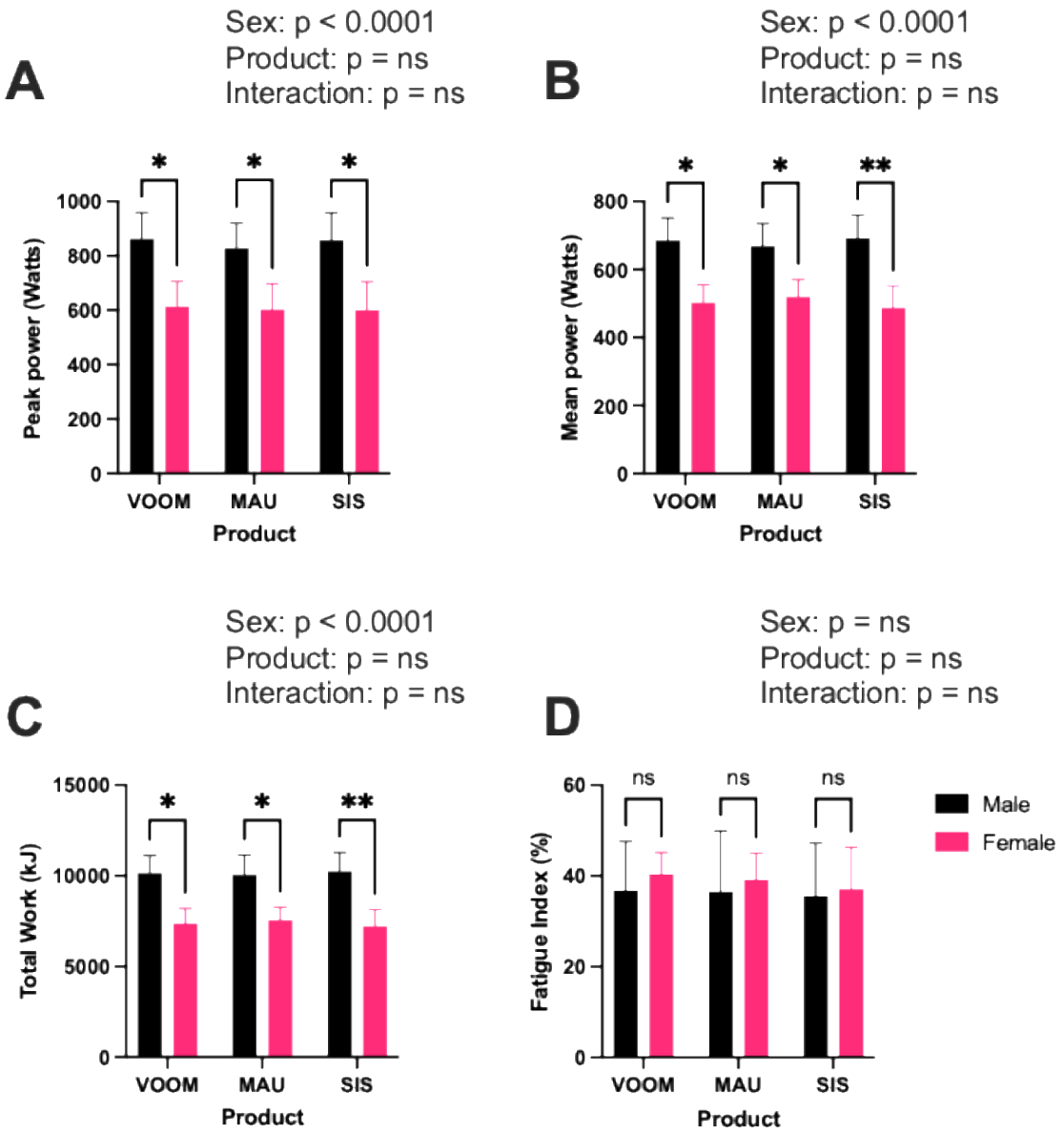

*Figure 15. Males produced significantly greater readings than females for (A) Peak power, (B) Mean power, and (C) Total work when averaged across all five sprints. (D) No significant effect of sex was shown for the Fatigue index ($p > 0.05$). *$p < 0.05$; **$p < 0.01$.*

3.6.2 Substrate utilisation was different between males and females

A two-way repeated measures ANOVA revealed a significant effect of sex on total carbohydrate oxidation ($p = 0.004$), but post-hoc tests revealed no significant differences. Maximum heart rate was not significant between males and females ($p = 0.1$).

The significant differences between males and females for the respective performance metrics and the significant effect of sex on total carbohydrate oxidation warranted further investigation to identify any effect of the products on performance, substrate utilisation and physiological responses to repeated sprint cycling.

3.6.3 Physiological responses during maximal sprint cycling

A two-way repeated measures ANOVA showed a significant effect of time on glucose concentration ($p < 0.0001$) but no effect of product (VOOM 4.5 ± 0.52 mmol/L; MAU 4.77 ± 0.42 mmol/L; SIS 5.08 ± 0.52 mmol/L, $p = 0.4$) or time x product interaction were shown ($p = 0.6$), as presented in Figure 16. The rate of change in glucose showed no significant effect ($p > 0.05$). Similarly, lactate concentration was influenced by time ($p < 0.0001$) but not product (VOOM 5.16 ± 3.09 mmol/L; MAU 5.08 ± 2.88 mmol/L; SIS 4.95 ± 2.92 mmol/L, $p = 0.9$) and showed no interaction effect ($p = 0.9$).

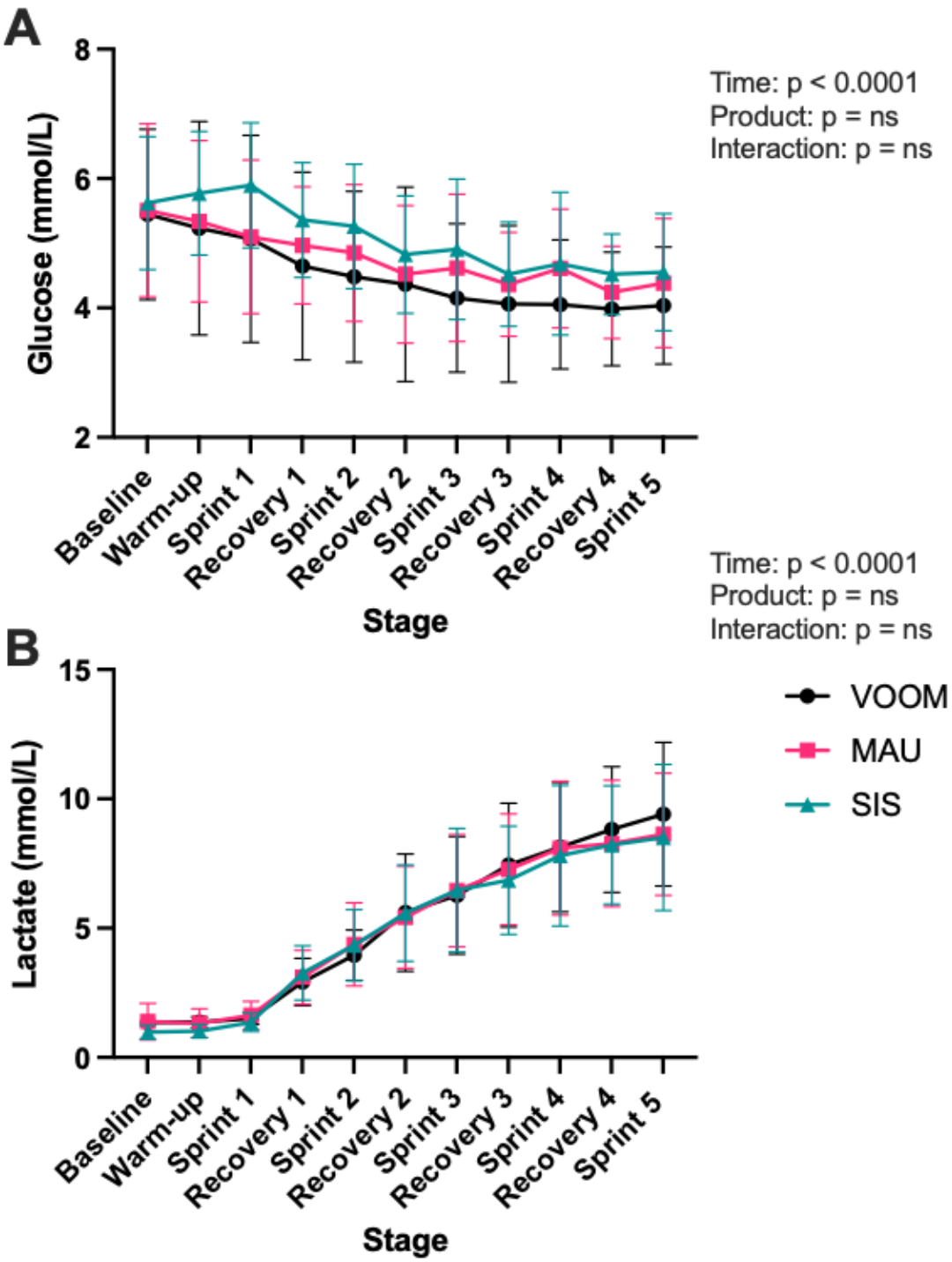

Figure 16. No significant differences between products in (A) Glucose or (B) Lactate concentrations.

A significant effect of time on potassium concentration was observed (p = 0.001), but not between products (VOOM 4.51 ± 0.24 mmol/L; MAU 4.68 ± 0.32 mmol/L; SIS 4.51 ± 0.28 mmol/L, p = 0.5) or time x product interaction (p = 0.7). Similarly, chloride levels were significantly affected by time (p = 0.02) but not product (VOOM 106.6 ± 0.87 mmol/L; MAU 106.3 ± 0.46 mmol/L; SIS 106 ± 0.66 mmol/L, p = 0.8) or time x product interaction (p = 0.6). No significant effect was found for sodium or calcium concentrations (p > 0.05).

As the data was non-normally distributed, a Friedman's test was conducted for heart rate. The Friedman test ranks data based on the relative position of each observation within its matched dataset. The results indicated significant differences in heart rate, X^2 (33) = 249, p < 0.0001. Dunn's multiple comparisons adjusted with a Bonferroni correction revealed no significant differences in heart rate (VOOM mean rank = 15, raw data mean = 126 ± 20.55 bpm; MAU mean rank = 16, raw data mean = 129.4 ± 20.27 bpm; SIS mean rank = 18, raw data mean = 131 ± 20.83 bpm, p > 0.05). Maximum heart rate was not significantly different between products (VOOM 164.2 ± 11.52 bpm; MAU 166.8 ± 11.26 bpm; SIS 169.4 ± 10.27 bpm, p = 0.2).

3.6.4 No effect of carbohydrate supplementation on substrate utilisation

A two-way repeated measures ANOVA revealed a significant effect of time for RER (p < 0.0001) but no effect of product (VOOM 1.08 ± 0.08; MAU 1.04 ± 0.06; SIS 1.05 ± 0.07, p = 0.4) or time x product interaction (p = 0.5). A significant effect of time on carbohydrate oxidation per minute was shown (p < 0.0001), but no effect of product (VOOM 2.39 ± 0.72 $g \cdot min^{-1}$; MAU 2.13 ± 0.46 $g \cdot min^{-1}$; SIS 2.31 ± 0.73 $g \cdot min^{-1}$, p = 0.6) or time x product interaction (p = 0.16), as shown in Figure 17. Total carbohydrate oxidation was not significantly different between products (VOOM 23.92 ± 5.79 g; MAU 21.3 ± 5.39 g; SIS 23.17 ± 6.99 g, p = 0.1). Subjects oxidised 53.15% of VOOM, 47.33% of MAU, and 51.49% of SIS.

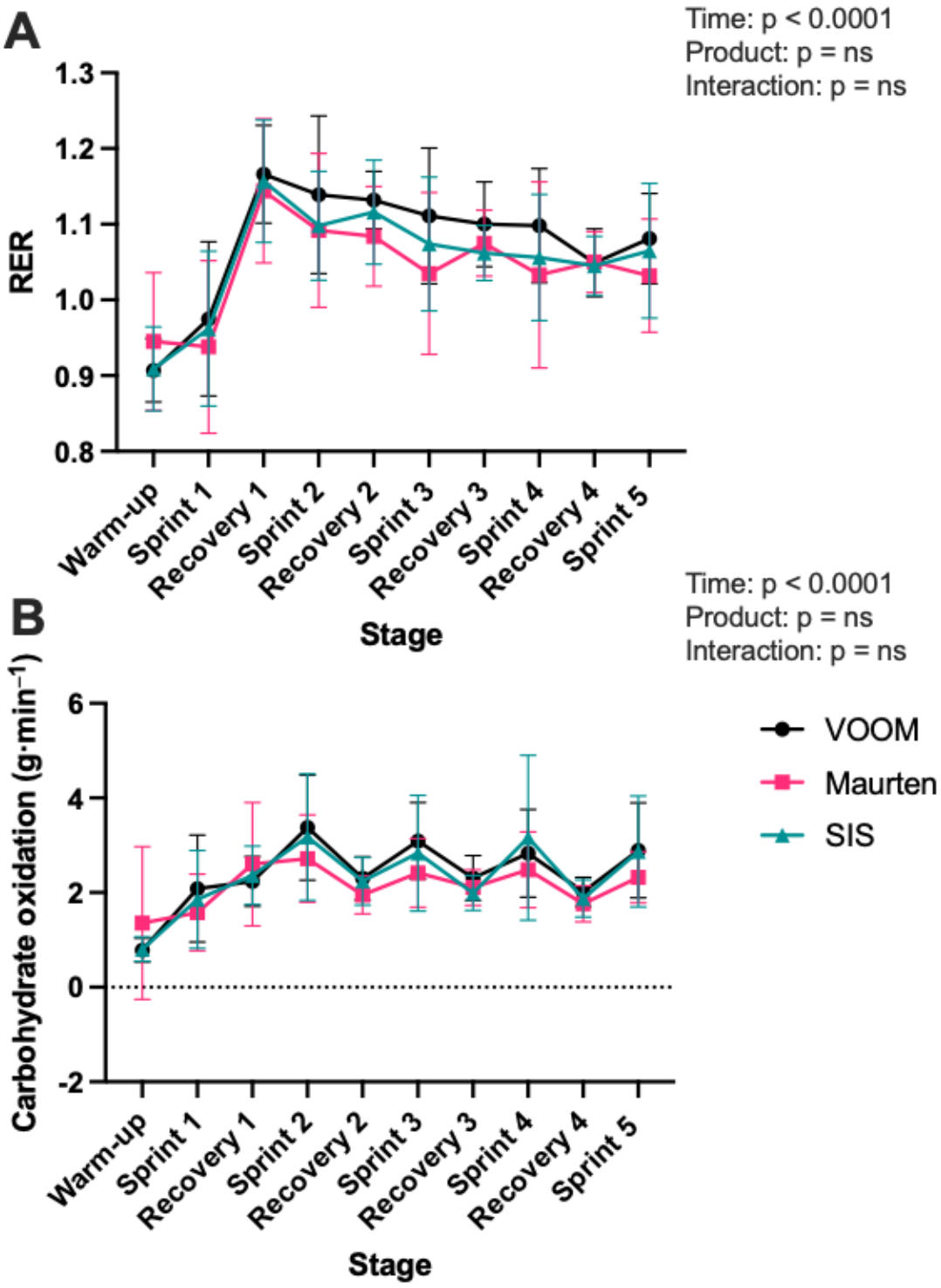

Figure 17. No significant differences in (A) Respiratory exchange ratio (RER) or (B) Carbohydrate oxidation per minute.

3.4.5 Performance metrics were comparable between products

A two-way repeated measures ANOVA for peak power per sprint revealed a significant effect of time ($p = 0.01$) but no effect of product (VOOM 736.7 ± 10.51 W; MAU 716.4 ± 21.2 W; SIS 728.5 ± 17.08 W, $p = 0.9$) or time x product interaction ($p = 0.9$). A similar trend was observed for mean power per sprint, where a significant effect for time was found ($p = 0.0002$), but no difference was detected between supplements (VOOM 593.1 ± 19.17 W; MAU 593.1 ± 19.63 W; SIS 589 ± 16.41 W, $p = 0.9$) or for the interaction effect ($p = 0.8$). Total work per sprint was also influenced by time ($p < 0.0001$) but not product (VOOM 8766 ± 290.1 kJ; MAU 8701 ± 251.5 kJ; SIS 8720 ± 263.1 kJ, $p = 0.9$) or time x product interaction ($p = 0.9$), as shown in Figure 18. No significant effect was found for the fatigue index (VOOM 38.57 ± 8.14%; MAU 38.28 ± 9.97%; SIS 36.33 ± 9.56%, $p = 0.2$).

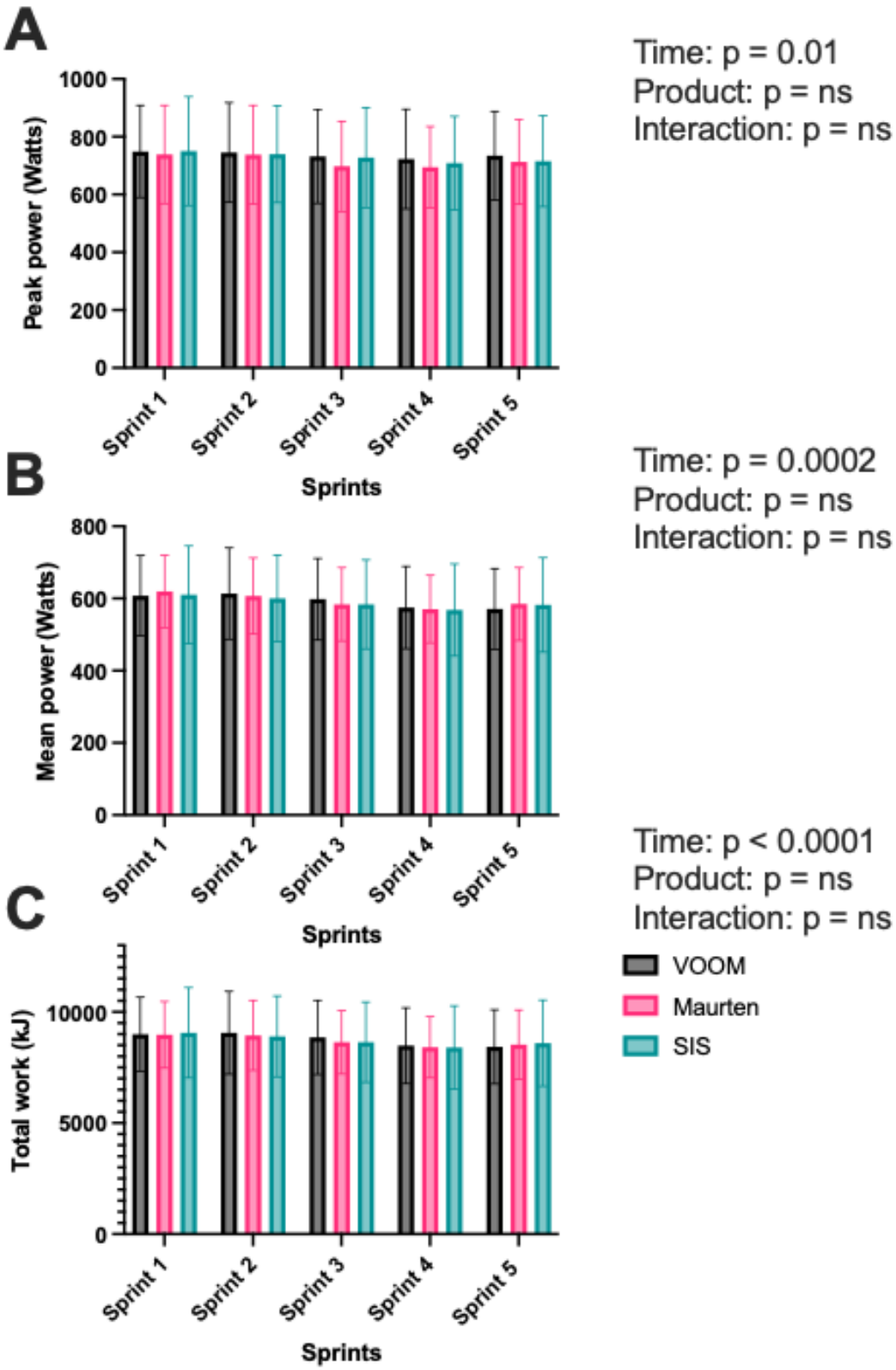

Figure 18. Comparable results in (A) Peak power, (B) Mean power, and (C) Total work per sprint between VOOM, MAU, and SIS.

No significant differences were found in gastrointestinal discomfort or RPE scores between products (P > 0.05), as shown in Table 6.

Table 6. Change in RPE and Gastrointestinal Discomfort Scores

	VOOM	MAU	SIS
Δ RPE	9.1 ± 1.79	8.2 ± 2.5	9.5 ± 1.36
Δ GI Scores	0.7 ± 1.06	0.6 ± 1.08	0.3 ± 0.66

Δ RPE = Change in the rating of perceived exertion. Δ GI Discomfort = Change in gastrointestinal discomfort score.

3.5 Discussion

This study sought to evaluate the effects of 45 g of carbohydrates from three widely used commercial carbohydrate energy supplements (VOOM, MAU, SIS) on repeated maximal sprint cycling performance. The results revealed no significant differences in physiological, performance, or perceptual outcomes following the consumption of these supplements. All three products, a glucose-fructose-based energy bar (VOOM), a fructose-glucose hydrogel (MAU), and a maltodextrin-based gel (SIS), produced similar metabolic and performance effects during repeated maximal sprints. These findings suggest that the specific type of carbohydrate supplement does not have a differential impact on sprint performance or metabolic responses.

There were no significant differences in peak power, average power, or total work per sprint, nor for the fatigue index averaged across all five sprints. There were also no significant differences in the change in RPE between supplements, indicating no effect of the supplements on perceptual changes to exercise. These findings suggest that the supplements tested in this study provided comparable effects on performance.

These findings are consistent with previous research indicating no, or little effect of carbohydrate supplementation on repeated sprint performance. Ingestion of an

8% carbohydrate solution showed no significant differences in peak or mean power output compared to a placebo (McMahon & Thornbury, 2020). Similarly to the present study, the only notable effect was a significant time effect ($p < 0.0001$) between the carbohydrate solution and placebo for the performance metrics. After ingesting maltodextrin-based supplements or a placebo (water), Gough et al. (2022) found no significant differences in repeated sprint ability test performance at 0 and 75 minutes during a 90-minute soccer-specific aerobic field test. Mean power output, peak power output, and fatigue index were not different between the carbohydrate supplements and the placebo. Similarly, Vigh-Larsen et al. (2024) found that a 7% carbohydrate solution (2:1 maltodextrin-fructose ratio) did not affect sprint performance, perceived exertion, or muscle glycogen depletion after three exercise periods consisting of 10 × 45-second bouts at 105% W_{max}, with 135-second rest intervals and 20 minutes between periods. Repeated sprint ability, assessed through 5 × 6-second sprints with 24-second recovery, also showed no differences between conditions. Furthermore, ingestion of a 45 g glucose-fructose (1:2 ratio) drink had no significant effect on a 'super-sprint' test (250 m swimming, 6 km cycling, 2 km running), with no differences found in performance or blood glucose concentrations (Pérez et al., 2024).

No significant differences were observed in gastrointestinal discomfort scores between the supplements compared in this study. This suggests that both the carbohydrate dose and composition of the supplements did not contribute to any significant discomfort that may impair performance. This aligns with previous research which demonstrates minimal gastrointestinal discomfort when consuming carbohydrate-based supplements (including carbohydrate hydrogels) during exercise, supporting their efficacy for use in competition or training (Baur & Saunders, 2021; Rowe et al., 2022). However, Guillochon et al., (2017) found that a solid carbohydrate bar may increase gastrointestinal discomfort, so it is recommended that individual athletes should look to test which carbohydrate supplements produce the least amount of gastrointestinal discomfort alongside a performance benefit.

3.6 Limitations

As with the first study, every effort was made to ensure the researcher remained blinded to the supplements taken in each trial. However, subjects were aware that one of the supplements was a bar and that the other supplements were gels. Again, this is unlikely to have caused any significant bias or affected the study findings.

A potential limiting factor of this exercise protocol is that subjects were not depleted of their glycogen stores before or during the exercise. This may have reduced the effect of the carbohydrate supplements consumed by the subjects. Exercise involving repeated sprints lasting ≤ 90 minutes (e.g., a football match) is unlikely to cause hypoglycaemia, indicating that glycogen stores are generally sufficient to maintain performance during this duration of exercise utilised in the present study (Bangsbro, 1994; Nicholas et al., 1995; Krustrup et al., 2006). Furthermore, the short sprint duration of 15 seconds likely relied primarily on PCr stores, which, alongside the 3 minutes of active recovery, may have been restored quickly enough to continue fuelling each subsequent sprint. This is consistent with the research of Germano et al., (2022) and Zouhal et al., (2024) who showed PCr stores, and subsequent exercise performance, can be recovered quickly during short bouts of active recovery. A future replication of this study may look to include a glycogen depletion protocol before exercise, such as those used by Kuipers et al. (1987), Wallis et al. (2008) and Podlogar et al. (2023), to better assess the ergogenic effects of carbohydrate supplementation.

While the carbohydrate supplements did not influence sprint performance directly, they may have played a role in maintaining blood glucose levels and aiding recovery between sprints (Baker et al., 2015; Krings et al., 2017). By slowing glycogen depletion, the carbohydrates consumed before exercise may have helped reduce the reliance on glycogen during repeated sprints, providing a source of energy that facilitated faster recovery. However, Vigh-Larsen et al., (2024) showed that carbohydrate supplementation at 55 g/h during repeated high-intensity cycling had no significant impact on muscle glycogen depletion, measured via muscle biopsies, compared to a placebo. The authors suggest that

the lack of significant difference in muscle glycogen depletion could be due to sufficient glycogen resynthesis during rest periods (up to 2 hours in total). The ingestion of carbohydrates may spare liver glycogen instead of muscle glycogen, leading to different metabolic effects. Since glycogen was not sampled in the present study, and with much shorter rest times (3 minutes in between sprints), these assumptions need to be made with caution.

3.7 Conclusion

There were no differences in physiological, performance, or gastrointestinal measures on repeated sprint cycling after consuming 45 g of carbohydrates from a glucose-fructose bar (VOOM), a glucose-fructose gel (MAU), or a maltodextrin-based gel (SIS).

4. CHAPTER 4: General discussion

4.1 Key findings

The main finding of this thesis was that, in a resting state, VOOM, a glucose-fructose energy bar, had a greater carbohydrate oxidation rate (both total and per minute) than a fructose-glucose hydrogel (MAU) and a maltodextrin-based energy gel (SIS). A higher carbohydrate oxidation rate is beneficial for exercise performance as it allows for more carbohydrates to be broken down for the production of ATP, which helps fuel muscle contractions and ultimately exercise performance. The faster this can occur following carbohydrate supplementation, the more rapid the performance benefits, delaying the onset of fatigue. However, during the repeated sprints used in this thesis, there were no changes in performance. Carbohydrate supplementation may be more likely to have an effect on exercise where carbohydrate oxidation is greater for longer periods of time, such as during high-intensity exercise which depletes glycogen stores at a greater rate, for example in team sports like rugby or football (Bradley et al., 2016; Mohr et al., 2022) or more specific glycogen depletion protocols, as used by Kuipers et al. (1987), Wallis et al. (2008) and Podlogar et al. (2023).

4.2 Efficacy and composition of carbohydrate compositions

A key aspect of this research was comparing the metabolic efficacy of three different carbohydrate energy products comprised of differing carbohydrate compositions: a glucose-fructose energy bar (VOOM), a fructose-glucose hydrogel (MAU) and a maltodextrin-based energy gel (SIS). Given the aim of this research was to establish how quickly each product provides carbohydrates, the glucose-fructose combination in VOOM was shown to oxidise carbohydrates at a greater rate than both MAU and SIS during the modified oral glucose tolerance test.

The choice between maltodextrin-fructose and glucose-fructose carbohydrate supplements depends on factors such as digestion, absorption, and oxidation rates. Maltodextrin, a glucose polymer, is often preferred in sports drinks and gels due to its lower osmolality than free glucose. This may reduce gastrointestinal distress and allow for faster gastric emptying (Jeukendrup, 2010; Rowlands et al., 2012; Jeukendrup, 2013). When combined with fructose, which is absorbed via the GLUT5 transporter, maltodextrin-fructose formulations enable higher carbohydrate oxidation rates (≥ 90 g/h) than glucose alone (60 g/h), as SGLT1 becomes saturated at this volume (Wallis et al., 2005; Jeukendrup, 2010; Jeukendrup, 2013; Podlogar et al., 2022). Also, maltodextrin has a less sweet taste than glucose, making it potentially more palatable, especially when consumed in high volumes such as ≥ 90 g/h (Wallis et al., 2005).

However, a glucose-fructose mixture may lead to higher total carbohydrate oxidation compared to a maltodextrin-fructose mixture. Glucose, in its free form, is immediately absorbed via SGLT1, whereas maltodextrin, a glucose polymer, must first be broken down into free glucose molecules by enzymes like amylase before being absorbed by SGLT1 (Wallis et al., 2005). While still rapid, this slight delay may be the reason why VOOM elicited a greater carbohydrate oxidation rate than SIS. Furthermore, solid carbohydrate sources often contain higher absolute amounts of carbohydrates per serving than gels, which could further contribute to a greater total oxidation over time (Stellingwerff & Cox, 2014).

While the ratio of glucose to fructose is not made clear by VOOM, the difference in oxidation rates between VOOM and MAU is of interest due to their similar formulation of glucose and fructose. MAU utilises a fructose-glucose ratio of 0.8:1 but elicited a reduced carbohydrate oxidation rate compared to VOOM. The primary reason for the slower oxidation rate in MAU is likely the encasing of the fructose-glucose combination within a hydrogel formula, which may slow the release of sugars into the bloodstream (King et al., 2020; Rowe et al., 2022).

The findings of this thesis suggest that a combination of glucose and fructose may be more optimal for rapid energy delivery than energy products primarily utilising maltodextrin. However, this increased carbohydrate oxidation shown at

rest was not translated into significant differences in metabolic or performance measures during repeated sprints, making it challenging to conclude whether VOOM, MAU or SIS directly improve exercise performance.

4.3 Translating findings of a modified resting oral glucose tolerance test to exercise conditions

The findings from the modified resting oral glucose tolerance test provide valuable insights into the carbohydrate metabolism elicited by three competing commercially available carbohydrate products. Isolating the compositions of VOOM, MAU and SIS allowed for direct comparisons in sixteen healthy Tier 2 athletes, revealing significant differences in carbohydrate oxidation rates. These differences may provide an insight into how each product may perform during exercise.

However, while the resting study demonstrated distinct metabolic responses to the different carbohydrate compositions, the physiological demands of exercise significantly alter substrate utilisation, gastric emptying, and intestinal absorption (Melzer, 2011; Smith et al., 2021; Gaskell et al., 2023). To evaluate the efficacy of these products during exercise, the second study aimed to determine whether these metabolic responses observed at rest translate into practical performance benefits and substrate availability during repeated bouts of sprint cycling in ten healthy Tier 2 athletes.

High-intensity sprint cycling primarily relies on anaerobic metabolism, with PCr and muscle glycogen serving as the dominant fuel sources (Vigh-Larsen et al., 2021; Vigh-Larsen et al., 2022a; Vigh-Larsen et al., 2022b). During repeated sprint efforts, glycogen breakdown accelerates, and as these stores become depleted, there is a greater reliance on carbohydrate oxidation from exogenous sources to maintain exercise performance (Baker et al., 2010; Archacki et al., 2024; Galvan-Alvarez et al., 2024). Therefore, sufficient carbohydrate availability is critical for sustaining power output across multiple sprints.

Carbohydrate supplementation may help delay glycogen depletion and support glycolytic flux, the rate at which glucose is metabolised via glycolysis to produce ATP, particularly when endogenous stores are depleted (Baker et al., 2015; Cao et al., 2025). Ingestion of rapidly digestible carbohydrates, such as glucose-fructose mixtures or maltodextrin-based formulations, enhances carbohydrate oxidation rates and improves endurance and high-intensity exercise performance (Wallis et al., 2005; Jeukendrup, 2010; Jeukendrup, 2013; Podlogar et al., 2022). Additionally, maintaining blood glucose concentrations through supplementation can reduce perceived exertion and delay fatigue (Cao et al., 2025).

The efficacy of different carbohydrate formulations may vary due to differences in absorption rates, gastric emptying, and substrate utilisation. Glucose-fructose mixtures enhance carbohydrate delivery by utilising multiple transportable pathways within the intestine, potentially increasing oxidation rates (Currell & Jeukendrup, 2008; Jeukendrup, 2010; Jeukendrup, 2013). In comparison, a glucose polymer like maltodextrin offers rapid glucose delivery via SGLT1 but lacks the multi-pathway absorption of glucose-fructose mixtures. While maltodextrin provides a steady energy source with a lower osmotic load, it may limit oxidation rates at high intake levels due to the saturation of SGLT1. In contrast, glucose-fructose mixtures enhance carbohydrate oxidation by utilising multiple transporters, improving energy availability during exercise (Podlogar et al., 2022).

The results of the exercise study did not show any significant differences between VOOM, MAU and SIS, indicating that the metabolic responses elicited by these products in the resting study may not directly enhance repeated sprint cycling performance. Given that carbohydrate supplementation is well documented to enhance exercise performance, the lack of difference between these products suggests that their specific formulations did not provide any advantages for repeat sprint cycling performance. This may be due to the similar metabolic effects between the products or perhaps, due to the absence of a non-carbohydrate comparator, making it difficult to determine whether carbohydrate supplement ingestion itself influenced performance. The discrepancy between resting and exercise conditions may be attributed to additional metabolic factors,

such as muscle glycogen availability and the relative contribution of endogenous vs exogenous carbohydrate sources during high-intensity exercise (Vigh-Larsen et al., 2021; Podlogar et al., 2022; Vigh-Larsen et al., 2022a; Vigh-Larsen et al., 2022b).

4.4 Importance of the research

Understanding the metabolic responses to different carbohydrate compositions under resting and exercise conditions is crucial for optimising sports nutrition strategies. This research bridges the gap between mechanistic laboratory studies and real-world applications, guiding recommendations for carbohydrate intake during exercise. By systematically investigating different carbohydrate compositions at both rest and during exercise, this programme of work contributes to refining nutritional strategies that support carbohydrate supplementation during exercise. Given carbohydrate-based supplements' prevalence among elite and recreational athletes, these findings have significant ecological validity and may help inform consumer choices. By providing comparative data on the efficacy of different carbohydrate formulations, this research can support evidence-based nutritional recommendations for athletes and recreationally active individuals.

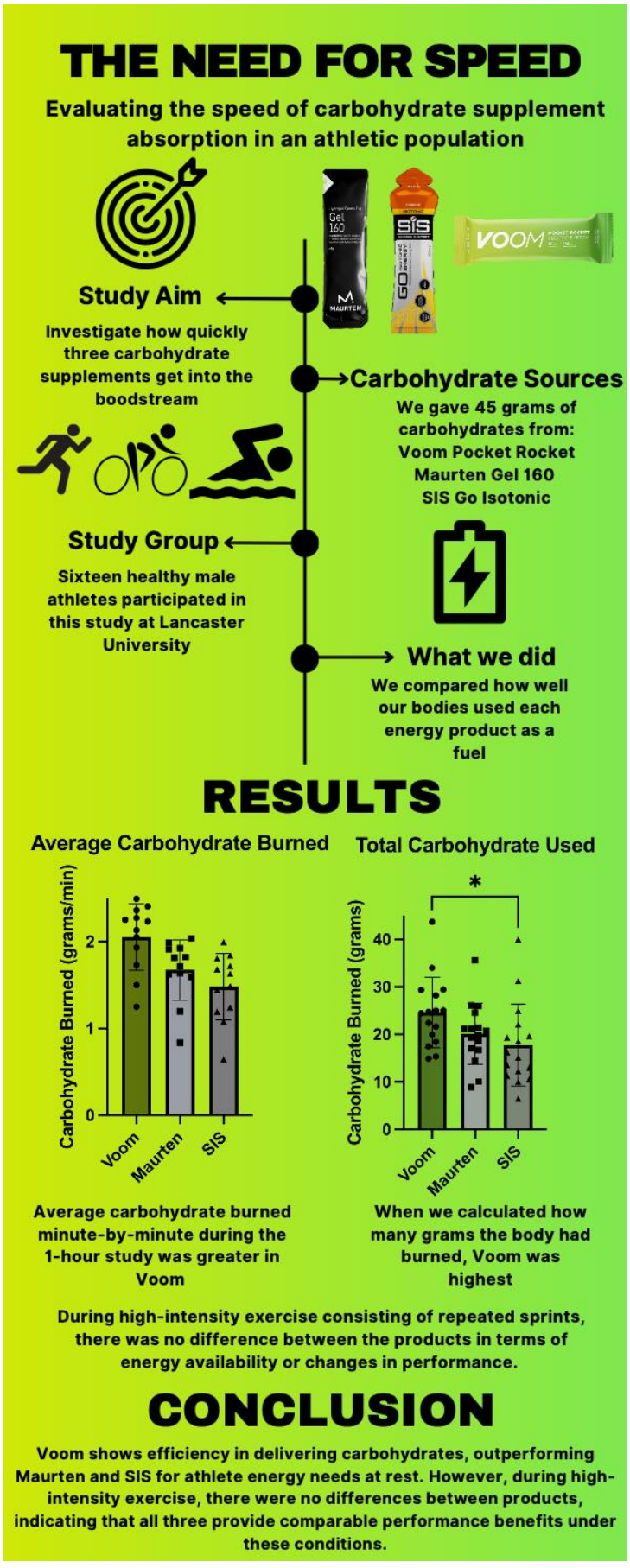

Figure 19. Infographic outlining study findings for public engagement

Figure 19. is an infographic intended for public use and is not a research figure. Its purpose is to translate research findings into an accessible format for consumers of carbohydrate energy supplements. By summarising key insights from the research, the infographic provides an evidence-based comparison of three popular products, helping consumers make informed choices based on their carbohydrate provision. While it reflects data from the research, it is designed as a communication tool rather than a formal scientific analysis.

4.5 Limitations

Despite the valuable insights gained from this research, several limitations should be acknowledged. Firstly, the studies did not utilise stable isotope tracers, which would have provided more precise and direct data on exogenous carbohydrate oxidation rates than utilising specific formulas (Frayn, 1963; Jeukendrup & Wallis, 2005). In the context of metabolic research, stable isotopes, such as ^{13}Carbon, typically in the form of ^{13}C-glucose, are used to track the oxidation and utilisation of specific nutrients within the body (Davies, 2020). This works by labelling specific carbon atoms with a carbohydrate molecule and monitoring its movement through the body. For example, Hearris et al., (2022) used ^{13}C-glucose-fructose to demonstrate that exogenous carbohydrate oxidation during prolonged cycling was comparable between different ingestion forms: fluid, gel, jelly chew or co-ingestion.

In this study, the absence of stable isotope tracers limits the ability to distinguish between the oxidation of ingested carbohydrates (exogenous) and the mobilisation of endogenous stores, potentially affecting the accuracy of metabolic assessments (Gonzalez & King, 2022). The reliance on specific formulas to estimate oxidation rates may introduce potential measurement errors. Incorporating stable isotope tracers would enhance the understanding of substrate utilisation in response to the different carbohydrate compositions within VOOM, MAU and SIS, providing more precise metabolic measurements. However, due to the cost constraints, stable isotopes could not be incorporated

into this research. Future research using stable isotope tracers could offer deeper insights into carbohydrate oxidation following VOOM, MAU and SIS consumption.

Furthermore, this research did not conduct muscle biopsies, which limits the ability to directly measure muscle glycogen changes following carbohydrate ingestion or other signalling within muscle in response to carbohydrate ingestion and exercise. While we did not measure glycogen in this thesis, there is a known relationship between RER and blood glucose concentrations, which can provide insight into substrate utilisation during exercise. However, RER and blood glucose concentrations do not directly reflect muscle glycogen levels. Instead, changes in these measures may indicate shifts in carbohydrate metabolism, which could influence glycogen utilisation over time.

Muscle biopsies are a well-established technique in exercise physiology and metabolic research, used to obtain small samples of skeletal muscle tissue for biochemical and histological analysis (Stout et al., 2025). In carbohydrate metabolism research, muscle biopsies allow for the direct assessment of muscle glycogen utilisation and storage, as well as enzyme activity and muscle fibre-specific adaptations to different nutritional and exercise interventions (Russo et al., 2021). The most commonly used method is the Bergström needle technique, which involves inserting a hollow needle into the muscle, typically the vastus lateralis, to extract a tissue sample (Bergström, 1962; Bergström, 1975). Future research incorporating muscle biopsies could provide a more detailed understanding of how these products affect muscle glycogen stores, offering valuable insight into the effectiveness of their different compositions and how they may impact performance and recovery. While this method is minimally invasive, it requires trained personnel and specialised laboratory facilities for proper processing and analysis, which were not available for this research.

A key limitation of this study was the absence of a non-carbohydrate comparator. While the aim was to compare the effects of different commercially available carbohydrate supplements, each utilising different formulations and compositions of carbohydrates, a non-carbohydrate comparator, such as water, could have

provided insight into how significant the observed effects were. Future studies may look to include a non-carbohydrate comparator or placebo to expand on this.

Additionally, the relatively small sample size (16 subjects at rest, 10 during exercise) of Tier 2 athletes may restrict the generalisability of the findings to broader athletic populations. Smaller sample sizes may reduce statistical power and limit the applicability of the findings to a wider population. Larger-scale replications with more diverse cohorts, for example, athletes of a higher athletic tier (McKay et al., 2021) may help improve the external validity of these findings.

Another potential limitation is the ecological validity of the research. The first study included only male subjects, which may limit the applicability of the results to female athletes, given the well-known sex differences in carbohydrate metabolism, such as hormonal fluctuations and use of contraception (Elliott-Sale et al., 2020). However, the second study improved ecological validity by including Tier 2 female athletes, making the findings more relevant to a wider athletic population. Nevertheless, further research with mixed-sex cohorts or direct comparisons between males and females would provide a more comprehensive understanding of sex-specific metabolic responses to carbohydrate ingestion.

In summary, while this research provides important insights into carbohydrate metabolism elicited by three popular commercially available energy supplements, addressing these limitations in future research could further refine understanding and enhance the applicability of the findings to real-world athletic settings.

4.6 Future directions

Building upon the findings of the studies included in this thesis, future research should further investigate the effects of these carbohydrate products and their specific compositions under a broader range of exercise conditions. While these studies provide valuable insights, additional research is required to determine their efficacy in more prolonged endurance-based activities, where sustained carbohydrate availability is of greater importance than intermittent sprint-based exercise (Jeukendrup, 2008). Understanding how VOOM, MAU and SIS

influence performance over extended durations will provide a more comprehensive assessment of their practical applications for endurance athletes.

Furthermore, future research should explore the impact of frequent supplementation with VOOM, MAU and SIS during exercise, as opposed to the administration of a single larger bolus (45 g) before exercise. This approach may better reflect real-world race strategies, where ingesting carbohydrates at specific time points during exercise is common, and may offer valuable insights into the most effective nutrition strategies for sustaining performance and delaying the onset of fatigue.

Another potential avenue of research is the role of carbohydrate supplementation in enhancing post-exercise recovery (Podlogar & Wallis, 2022). Specifically, future research may examine whether the consumption of VOOM, MAU or SIS contributes to improved muscle glycogen resynthesis, reduced markers of muscle damage and enhanced overall recovery following both endurance and high-intensity exercise (Fuchs et al., 2019; Craven et al., 2021). These findings may have significant implications for athletes seeking to optimise both performance and recovery strategies and to ensure training remains consistent over time.

Throughout these research themes, incorporating the techniques discussed above, such as muscle biopsies and stable isotope tracers would further enhance the understanding of the metabolic pathways involved in carbohydrate utilisation and storage by tracking substrate oxidation rates and glycogen synthesis in response to different carbohydrate compositions.

Finally, a broader consideration for this area of research is the individual variability in response to different carbohydrate compositions and supplementation strategies. Factors such as genetic predisposition, training status, and gut microbiota composition may influence carbohydrate metabolism, highlighting the need for personalised nutrition strategies (Jeukendrup, 2014; Podlogar & Wallis, 2022). Tailoring carbohydrate intake based on these individual factors could optimise performance, recovery, and overall athlete well-being.

Future research should explore how these variables, along with personal preferences, impact the effectiveness of carbohydrate supplementation, ultimately refining strategies to enhance endurance performance and training consistency.

4.7 Overall conclusion

This thesis investigated the impact of different commercially available carbohydrate energy supplements on carbohydrate metabolism and exercise performance. The first paper in this thesis demonstrated that the VOOM glucose-fructose bar delivers carbohydrates as quickly, or possibly faster than both the MAU fructose-glucose hydrogel and the SIS maltodextrin-based gel, suggesting that it could be an effective alternative for athletes seeking rapid glucose availability. However, the second paper showed no significant differences in physiological, performance, or gastrointestinal responses during repeated sprint cycling between products. These findings indicate that while the rate of glucose absorption may vary between supplements, they appear to have similar effects on performance and gastrointestinal comfort during high-intensity exercise.

5. Appendix

5.1 Medical screening form aligned to the American College of Sports Medicine (ACSM) safety to exercise guidelines:

Need for speed - Evaluating the Speed of Carbohydrate Supplement Absorption in an Athletic Population - Screening Questionnaire		
Risk Factors	**Risk Factor**	**No Risk Factor**
Q1. **Age** _____years Male Female	**≥45** **≥55**	**<45** **<55**
Q2. Are you a current **smoker**? *If yes, how many cigarettes do you smoker per day?* _____ If no, have you ever smoked? *If yes, how long has it been since you quit?* _____ *Are you exposed to environmental tobacco smoke?*	**Yes** Yes† *Yes†*	**No** No *No*
Q3. **Family history:** Have any parents or siblings had a heart attack, bypass surgery, angioplasty or **sudden death*** prior to 55 years (male relatives) or 65 years (female relatives)?	**Yes**	**No**
Q4. **Physical inactivity:** In the past 3 months, have you performed at least 30 minutes of activity on at least 3 days per week	**No**	**Yes**
Q6. **Anthropometry:** Body mass _____ kg Height _____ cm **Body mass index** _____kg/m^2 Body Composition:	**≥30**	**<30**
TOTAL NUMBER OF RISK FACTORS (Bold only) † Include as a risk factor if ≤6 months *If YES to **<u>early</u> sudden death** in family history advise pre-participation screening for SCD with GP **If BP ≥140/90mmHg after 2 measurements advise GP visit ^ If ≥5.55 – ≤6.94 (NF ≥7.77 – ≤11.04) class as risk factor, if >6.94 (NF >11.04) class it is a RF and HoD		

^^ If HDL ≥1.55mmol/L, subtract 1 from the total risk factors	

NOTE: Risk factors are collected for pre-examination evaluation of CVD risk assessment and not for decision making related to medical referrals

Signs or Symptoms		
Q7. Do you ever have pain or discomfort in your chest or surrounding areas (neck, jaw, arms or other areas)?	Yes	No
Q8. Are you ever short of breath at rest or with mild exertion?	Yes	No
Q9. Have you ever experienced dizziness, fainting or loss of consciousness during or shortly after exercise?	Yes	No
Q10. Have you ever been short of breath at rest in the recumbent position or had an attack of breathlessness in the middle of the night which was relieved by sitting up?	Yes	No
Q11. Do your ankles ever become swollen (other than as a result of an injury)?	Yes	No
Q12. Do you ever have palpitations (the unpleasant awareness of the heart beating in your chest) or an unusual period of rapid heart rate?	Yes	No
Q13. Do you ever suffer from burning or cramping sensations in your legs, brought on by exertion and relieved after 1-2 minutes of rest?	Yes	No
Q14. Has a doctor ever said you have a heart murmur?	Yes	No
Q15. Do you feel unusually fatigued or find it difficult to breathe with usual activities?	Yes	No
SIGNS/SYMPTOMS OF DISEASE	**YES**	**NO**

Personal History of Disease		
Q16. Heart disease	Yes	No
Q17. Peripheral vascular disease	Yes	No
Q18. Cerebrovascular disease (e.g. stroke)	Yes	No
Q19. Asthma (if controlled no further action)	Yes	No
Q20. Chronic obstructive pulmonary disease	Yes	No
Q21. Diabetes mellitus Type 1 Type 2	Yes Yes	No No
Q22. Renal (kidney) disease	Yes	No
Q23. Liver disease	Yes	No
HISTORY OF DISEASE	**YES**	**NO**

Other Conditions/Additional questions		
Q30. Are you or have you recently been pregnant?	Yes	No
Q31. Are you taking any prescription medications? List:	Yes	No
Q31. Do you have any blood clotting disorders? Are you taking any prescription medications for this, for example, Aspirin? List:	Yes	No
Q31. Do you have any known allergies? List:	Yes	No
Q31. Are you following any specific diets? (e.g. Keto, Atkins) List:	Yes	No
Q32. Have you had any **alcohol** to drink in the last 24 hours? *If yes,* how many units? _____ units how long ago? _____ hours	Yes	No
Q32. Have you had any **caffeine** to drink in the last 24 hours? *If yes,* how much? (e.g. a cup of coffee is ~200ml) _____ ml how long ago? _____ hours	Yes	No
Q33. Are there any other factors that may affect your results today? E.g. viral infection, injury, smoking, exercise within the past 24 hours, recreational drugs. Details: _____	Yes	No

RISK ANALYSIS		
RISK FACTORS	YES	NO
PARTICIPATES IN REGULAR EXERCISE	YES	NO
SIGNS/SYMPTOMS *Asymptomatic* *Symptomatic*	YES YES	NO NO
HISTORY OF DISEASE (CV, Metabolic or Renal)	YES	NO

ACSM RECOMMENDATION	Action/Medical Clearance: Recommended Intensity: Progression:

Declaration
I confirm that the above information which I have provided to Lancaster Medical School (Lancaster University) is true and accurate to the best of my knowledge and belief and I understand that I must notify promptly of any changes to the information.
Student/Participant signature: **Date:**
Assessor signature: **Date:**

This screening form has been developed in collaboration with Costas Tsakirides (Leeds Beckett University) and in line with the 2018 ACSM Guidelines for Exercise Testing and Prescription.

5.2 Modified Gastrointestinal Symptom Rating Scale (GSRS), (Svedlund et al., 1988)

During this study how often have you been troubled by abdominal pain or abdominal cramps?

0. Never
1. Rarely
2. Sometimes
3. Often
4. All the time

During this study, how much of a problem have you had with bloating?

0. No problem
1. A minor problem
2. Some problem
3. A significant problem
4. A major problem

During this study, how much of a problem have you had with excessive wind?

0. No problem
1. A minor problem
2. Some problem
3. A significant problem
4. A major problem

During this study, how much of a problem have you had with loose stools?

0. No problem
1. A minor problem
2. Some problem
3. A significant problem
4. A major problem

How often During this study have you had an urgent need for your bowels to open or a sudden need for a toilet?

0. Never
1. Rarely
2. Sometimes
3. Often
4. All the time

During this study, how often have your bowel motions been oily or greasy?

0. Never
1. Rarely
2. Sometimes
3. Often
4. All the time

During this study, how much of a problem have you had with foul smelling stools?

0. No problem
1. A minor problem
2. Some problem

3. A significant problem
4. A major problem

How often has the feeling of fatigue or of being tired and worn out been a problem for you During this study?

0. Never
1. Rarely
2. Sometimes
3. Often
4. All the time

5.3 Borg (1982) 6-20 rating of perceived exertion (RPE)

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

6. List of Abbreviations

°C = Degrees Centigrade

ACSM = American College of Sports Medicine

ADP = Adenosine Diphosphate

ANOVA = Analysis of Variance

ATP = Adenosine Triphosphate

BM = Body Mass

BMI = Body Mass Index

bpm = Beats Per Minute

CHO = Carbohydrate

Cl^- = Chloride

ELISA = Enzyme Linked Immunosorbent Assay

$FADH^2$ = Flavin Adenine Dinucleotide + Hydrogen)

g = Grams

$g \cdot 5\text{-}min^{-1}$ = Grams Per 5 Minutes

$g \cdot min^{-1}$ = Grams Per Minute

g/h = Grams Per Hour

g/kg = Grams Per Kilogram

GI = Gastrointestinal

GLUT2 = Glucose Transporter 2

GLUT5 = Glucose Transporter 5

HCLF = High Carbohydrate Low Fat

K^+ = Potassium

kcal = Kilocalories

kg = Kilograms

kg•kg-1 = Kilograms Per Kilograms

kJ = Kilojoules

km = Kilometres

L/min = Litres Per Minute

LCHF = Low Carbohydrate High Fat

m = Metres

MAU = Maurten Gel 160

mg = Milligrams

min = minutes

ml = Millilitres

mmol/L = Millimoles Per Litre

Mmol/L/min = Millimoles Per Litre Per Minute

Na^+ = Sodium

NAD+ = Nicotinamide Adenine Dinucleotide, Oxidised Form)

NADH = Nicotinamide Adenine Dinucleotide + Hydrogen)

nm = Nanometre

PCr = Phosphocreatine

pH = Potential of Hydrogen

RCF = Relative Centrifugal Force

RER = Respiratory Exchange Ratio

RPE = Ratings of Perceived Exertion

rpm = Revolutions Per Minute

RQ = Respiratory Quotient

SD = Standard Deviation

SGLT1 = Sodium Glucose Transporter 1

SIS = Science in Sport Go Isotonic Energy Gel

TCA Cycle = Tricarboxylic Acid Cycle

$\dot{V}CO_2$ = Volume of Carbon Dioxide

$\dot{V}O_2$ = Volume of Oxygen

VO_2 max = Maximum Volume of Oxygen

VOOM = Voom Pocket Rocket Electro Energy Bar

W = Watts

Watts/s = Watts Per Second

W_{max} = Maximal Workload/Maximum Wattage

X^2 = Friedman's Statistic

µL = Microlitres

µU/mL = Micro Units Per Millilitre

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