Carbohydrate for endurance athletes in competition: Assessing knowledge and nutritional practices.

Gemma Sampson

A thesis submitted in partial fulfilments of the requirements of Liverpool John Moores University for the degree of Professional Doctorate in Applied Sports and Exercise Science

May 2021

Abstract

A key role of a practicing sports dietitian working with competitive endurance athletes is to translate complex information, educate and support athletes to make nutritional changes to their dietary behaviour for improved performance outcomes. Current carbohydrate (CHO) guidelines based upon a wealth of literature demonstrate clear performance benefits when endurance athletes compete with optimal CHO availability. Despite this strong scientific evidence and sports nutrition guidelines recommending CHO intakes to enhance endurance sports performance, a clear mismatch still exists between current guidelines and practice amongst endurance athletes as evidenced in the Literature Review (**Chapter 2**). With this in mind, the aim of this Professional Doctorate thesis was to investigate whether athletes fail to consume optimal CHO in competition because they were *unaware* and lack knowledge of the current CHO guidelines, have difficulties with *translating* knowledge into practice, have *personal beliefs* or are exposed to *external factors* which influence their dietary intake within competition.

To systematically assess CHO knowledge, we first needed to develop a tool and methodology to do so. Thus, the aim of Study 1 (**Chapter 3**) was to develop and validate a CHO specific nutrition knowledge assessment tool, based upon contemporary carbohydrate guidelines. The Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q) consists of 25 questions divided into 5 subsections: CHO metabolism, loading, pre-race meal, during race and recovery with each subsection worth 20 points resulting in a total maximum possible score of 100. A between-groups analysis of variance assessed construct validity between the general population (GenP; $n = 67$), endurance athletes (EA; $n = 145$), and registered sports dietitians/nutritionists (SDN; $n = 60$) with expected increasing levels of knowledge respectively. As expected, there was increasing level of knowledge between populations with a significant difference in CEAC-Q total and subsection scores (mean ±SD) observed between all pairwise comparisons; GenP (17 ±20 %, 3 ±5), EA (46 ±19 %, 9 ±5) and SDN (76 ±10 %, $p = < 0.001$, 15 ±4 %, $p = 0.001$), respectively. The CEAC-Q took athletes an average 10:36 ±07:45 minutes to complete online. These data demonstrate that CEAC-Q is a new psychometrically valid, practical and time-efficient tool for practitioners to assess athletes' knowledge of CHO for competition in less than 10 minutes, allowing for quick and accurate identification of knowledge gaps to nutrition strategies to optimise performance.

Having developed a suitable CHO knowledge assessment tool in Study 1 (**Chapter 3**), the aim of Study 2 (**Chapter 4**) was to assess current knowledge levels and identify knowledge gaps on an international cohort of EA. The CEAC-Q was completed online by EA (n = 1016) actively competing in endurance sporting events (cycling, triathlon and running) with mean CEAC-Q total and subsection scores of 50 ±20% and 10 ±5, respectively. Multiple regression determined that years of competitive experience, competitive level and a sports nutritionist influence were positively related to CEAC-Q scores. Clear knowledge gaps transpired where correct knowledge of current CHO guidelines was shown by 28% (n = 284) for CHO loading, 45% (n = 457) for the pre-competition meal, 48% (n = 487) for during competition lasting >2.5 h and 29% (n = 296) for post-competition recovery. The CEAC-Q identified common gaps in knowledge of CHO guidelines that require further education that may partially explain why athletes fail to meet them within competition.

Since Study 2 (**Chapter 4**) identified clear knowledge gaps of current CHO guidelines, the aim of Study 3 (**Chapter 5**) was to assess the relationship between knowledge of CHO guidelines and dietary intake within athletes competing in real-world competition. Amateur and elite athletes (n = 50) competing in international cycling, triathlon and marathon events recorded dietary intake for the 24 h period before competition (CHO loading) and pre-competition meal using Remote Food Photography Method, with intake during collected by recall immediately after competition. Intake was compared against the CEAC-Q scores and knowledge of current guidelines. Correct knowledge of current guidelines was shown by 36% (n = 18) of athletes for pre competition day CHO loading and 64% (n = 32) for CHO intake during events. In relation to practice, 84 % (n = 42) athletes failed to achieve pre-competition day CHO intake guidelines by ingesting 6.5 ±2.2 $g{\bullet}kg^{-1}$ and 68% (n = 34) failed to achieve CHO intake during competition guidelines by ingesting 52 ±2 $g{\bullet}h^{-1}$. No association was evident between knowledge of CHO guidelines and dietary intake for CHO loading, the pre-event meal or during competition. Knowledge may be a facilitator, but it seems evident that actual dietary choices within competition are strongly influenced by factors other than theoretical knowledge.

Given that Study 3 (**Chapter 5**) observed endurance athletes who identified CHO guidelines did not consistently translate this knowledge into practice, Study 4 (**Chapter 6**) aimed to explore factors explaining the lack of association between knowledge of CHO guidelines and actual CHO loading and during competition intakes. Semi-structured interviews were conducted 7 - 14 days post-competition in the same 50 amateur and professional endurance athletes from Study 3 (**Chapter 5**). Interview transcripts were first analysed inductively line-by-line using reflexive thematic analysis. A deductive approach then applied the COM-B model of behaviour change as a coding framework to inform a position of all factors influencing the *capability, opportunity* and *motivation* of endurance athletes to apply knowledge to dietary practice 24 h before and during competition. Endurance athletes did not achieve CHO loading guidelines due to low knowledge and skills (*capability*), or personal beliefs and fears that limited their *motivation* to increase CHO intake. Conversely, despite knowing CHO guidelines during competition, athletes were frequently exposed to external factors (weather, intensity, regulations) during competition that limited the *opportunity* to consume planned CHO intake. Having identified key limiting factors between knowledge and practice, these can be suitably addressed via targeted nutrition education, interventions and behaviour change techniques.

In summary the data presented in this thesis demonstrate that the CEAC-Q is a time-efficient tool that sports dietitians can use collectively with dietary records and motivational interviewing (nutritional counselling) to identify gaps in knowledge, beliefs and external factors that influence why athletes fail to achieve recommended CHO within competition. These can subsequently guide appropriate education and dietary interventions using the most appropriate behaviour change techniques that enhance the relevant *capability*, *opportunity* or *motivation* for athletes to change their CHO intake to better align with CHO guidelines for competition.

Acknowledgements

First, I wish to thank my supervisor Dr Jose Areta for his constant reassurance, support, guidance and belief in me and the professional impact of my research throughout this journey with multiple house moves, job changes and the disruption of COVID-19. He reinforced the importance of being systematic with my research, provided prompt thorough feedback and kept me accountable. He regularly reminded me that this is a marathon, not a sprint, and how taking small daily steps helped me achieve my goals. So much has come from that chance meeting in a coffee shop in Liverpool!

Thank Professor James Morton for supporting my goals for this Professional Doctorate and challenging me with the questions of "*Where are you going? Where do I want to go in life? If I don't know where I'm going, I won't get there*". Despite having always had a strong commitment to improve my professional practice, I have no doubt that without this challenge and reminder to focus and record what I am working towards, I wouldn't be where I am today.

I am grateful for the mentoring Zoe Knowles shared, the skills in qualitative research and motivational interviewing I learned through her guidance. Sports science is a heavily male-dominated domain, especially in the field of professional cycling, and she has been a great example as a female sports science researcher.

I can't thank Carol Wain enough for her support, for encouraging me to make leaps of faith into unchartered waters as a sports dietitian, leaving the security of paid work to follow my heart and support the 'crazy' decision to relocate to Girona (Spain) at the same time as beginning my Professional Doctorate. Difficult this journey has been, but I have no doubts that many professional opportunities would never have eventuated without taking this risk.

It is impossible to do a Professional Doctorate alone and I will be forever grateful for the many friends who supported me through this journey, fed me and helped me to develop better work-life balance. In particular, Kat and Kim have created an amazing work environment at Forca13, Helen Aldred has kept me on track with our weekly accountability meetings, Sarah Bonner has given me regular reality checks and Pre has ensured I laugh daily.

To all the athletes who participated in my studies, I have loved our conversations and appreciate the time you took to fill out my questionnaires and look forward to supporting you with your future performances.

Last but not least, I am incredibly grateful for my family and parents back in Australia who have supported my extended leave of absence out of Australia this past decade and for tolerating my ‘never ending’ study. Finally, my studying days are over! Although I perhaps am not ready to go and ‘get a real job,’ I am excited to apply and build the findings of my Professional Doctorate into my daily practice and sports nutrition consultancy as a sports dietitian.

Declaration

I declare that the work within this thesis, which I now submit for assessment on the programme of study leading to the award of Professional Doctor of Applied Sports and Exercise Science is entirely my own. No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of variance
BCW	Behaviour Change Wheel
BM	Body mass
CEAC-Q	Carbohydrate for Endurance Athletes in Competition Questionnaire
CHO	Carbohydrate
COM-B	Capability, Opportunity and Motivation - Behaviour change model
CPD	Continuous Professional Development
EA	Endurance Athlete
F	Female
GenP	General Population
ISLAGIATT	It seemed like a good idea at the time
LJMU	Liverpool John Moores University
M	Male
NA	Not applicable
NS	Not Specified
RFPM	Remote Food Photography Methodology
SDA	Sports Dietitians Australia
SENR	Sport Nutrition Exercise Register
SDN	Sports Dietitian/Nutritionist
TDF	Theoretical Domains Framework
%TE	Percentage of total energy

Chapter 1

Introduction

1.1 Researcher Positionality

I am an Advanced Sports Dietitian who has run my own successful sports nutrition consultancy since 2017. Upon commencing my Professional Doctorate, I had over 10 years of experience working as a dietitian in a variety of clinical, industry and professional roles residing in 3 countries over this period (see **Figure 1**). My role as a sports dietitian is to provide nutrition education, guidance, counselling and interventions to the athletes I work with that improves their dietary behaviours and optimises their competitive performance. My clients, the athletes I work with are typically paying me to help them achieve their desired results as rapidly as possible. Subsequently, my personal background, philosophy for my business and professional experience changing the dietary behaviours of the athletes plays an inherent role in the research I conduct. I aim to encapsulate how these factors changed and influenced my research, business and practice throughout the life-course of the Professional Doctorate within each research orientation commencing and reflective pauses concluding each chapter within this thesis.

Figure 1. Timeline of academic, professional qualifications, roles and location

1.2 Professional Background and objectives

The primary objective of my Professional Doctorate is to develop my capability as a sports dietitian to work and research within my professional context supporting endurance athletes. A key motivation to commence the Professional Doctorate journey was to incorporate a more effective, evidence-based approach within my business and in the way I assess, advise and educate athletes to optimise their dietary intake and influence behaviour change.

Professionally, the goal to complete a Doctorate in sports nutrition was first identified in 2008 as part of the mandatory Dietitians Australia Accredited Practicing Dietitian continuing practicing development (CPD) pathway. Despite this goal, my career progression was diverted, with multiple changes in roles and country relocations (**Figure 1**). In retrospect this was due to a lack of clear vision and direction for my life professionally and personally and I lived reactively rather than proactively. A key turning point for my career occurred during a lecture delivered by Dr (now Professor) James Morton who asked, "*Where are you going? Because if you don't know you'll never get there'*. He encouraged us '*keep focusing on your vision, values and behaviours. Don't be a builder turning up for work not knowing what you want to build every day!"* (21.2.17). It was a lightbulb moment that prompted me to reflect on my goals and visions (personal and professional) to build my life with intention and direction rather than the scattered '*let's see where we end up'* approach that I had used prior to this date. Here onwards I began regularly incorporating reflective practice within my personal and professional life, linking daily activities and learnings to my future goals.

I identified that "*I want to make a difference in improving performance as well as sustainable changes to behaviour… to undertake sports nutrition research as a practitioner that can be practically applied to answer an athlete's questions (19th July 2017)."* The financial success of a private practice with satisfied and returning clients is dependent upon those clients getting tangible and timely results to justify their initial or ongoing investment. What could I do or say differently as a dietitian when educating my athletes so that they changed their diets sooner and made the changes that I knew from clinical experience and practice could benefit their weight or competitive performance?

Just telling an athlete to do something didn't guarantee that they would change anything, and I wanted to help my athletes achieve results sooner, rather than later as captured in my reflective notes: *"Why am I effective to my clients, what is it that I bring to the table? My ability to build relationships and empathise, my personality, values, communication and counselling skills all influence behaviour change - why athletes want to continue working with me, why they find me useful, why they trust me, and stick around without becoming dependent upon me" (2nd March 2017).* This realisation heightened my desire to improve the strategies and techniques I employed within my professional practice (such as education, cooking demonstrations, meal plans or role modelling) to more effectively support positive changes in dietary behaviours of my athletes that they continued whether I was present or not.

I increasingly saw the value of psychology on behaviour change and was hungry to learn more and build this into my business and practice. This led me to organise a meeting with Dr David Tod, a sports psychologist at LJMU to learn how to apply behaviour change into my professional practice as a sports dietitian to support faster results for my athletes. He introduced me to the Professional Doctorate programme where this personal and professional development journey began.

Self-audit using the Vitae Researcher Development Framework identified 3 key areas for planned professional development to enhance my personal effectiveness, engagement, influence and impact as a sports dietitian through the Professional Doctorate process: 1) Professional and career development; 2) Self-management skills; 3) Communication and dissemination skills.

Thus, my personal and professional objectives to commence a Professional Doctorate were:

1. To enhance my research skills and experience as an applied researching sports dietitian.
2. Further develop my time management skills, responsiveness to change and work-life balance as a self-employed sports dietitian.
3. To develop communication and dissemination skills both with my professional peers and athletes.
4. Use these research findings within my personal practice as a sports dietitian to more effectively educate athletes and deliver sports interventions that support changes in dietary behaviour.

As an applied practitioner, the intended approach to demonstrate achievement of these objectives was through reflective practice knowing-in-action, reflection-in-action and reflection-on-reflection-in-action (Schon, 1983). This involved using an unstructured and structured approach of regular reflective notes based on 5 questions: what went well, what didn't go well, what did/didn't I do that resulted in performance and what could be done differently next time (Gibbs, 1988). The reflective pauses at the conclusion of each chapter provide evidence of this developmental journey throughout the Professional Doctorate.

1.3 Research Background

At the time I began my Professional Doctorate I was self-employed and had recently relocated to Girona in Spain. Prior to relocating I held a nutrition clinic in Liverpool and discovered that a physical location was a barrier for amateur athletes because of a) the time and distance to travel or b) because they used Saturdays for long training sessions. Working remotely and online with athletes was a good business approach to help break down that barrier and provide access to a sports dietitian at a time and place convenient to the client. I planned to build online nutrition courses for athletes focusing on sports nutrition for training and competition and wanted to assess how effective this method was to educate and change behaviour of athletes.

I also personally trained and competed in endurance events and frequently observed that my training partners and endurance athletes in my practice rarely ate CHO foods in training and competition. As a sports dietitian, I was well aware of the performance benefits available when training or competing with optimal CHO availability and I wondered why athletes were so against eating CHO during exercise? There appeared to be this culture that I call '*eating is cheating'* within cycling, where athletes boasted about how long they could ride fasted – even when it cost their performance. They seemed to believe that eating CHO would make them fat and didn't fuel their training, which influenced how they fuelled within competition.

These amateur athletes frequently asked for free sports nutrition advice during our training sessions, but rarely believed, acted upon my suggestions or engaged in my professional services. I would hear about the latest fad diet they used to lose weight and how they had spent >£5000 on a new bike that shaved off 500 g weight to make them faster at their next competition. Yet they considered a sports nutrition consultation costing <£100 that would help them lose 5 kg of weight or develop a race nutrition plan, expensive and not a valuable investment to optimise their performance. I found it surprising that athletes would spend money on expensive pieces of equipment that might save seconds on their race performance, yet were unwilling to consider investing in nutrition, where bigger performance gains could be made. A key role of a sports dietitian is to positively influence nutrition choices of athletes in training and competition to optimise performance. Yet, as I frequently observed in my own practice and since in the literature, few athletes sought professional nutrition advice when aiming to improve their performance. Something needed to change in my approach to attract clients to sustain a financially viable business, and in the way I communicated nutrition advice, so athletes took action upon the dietary changes I recommended.

Although the research studies evolved throughout the Professional Doctorate journey (as detailed in the research orientations and reflective pauses), my initial goal was to design nutrition interventions to change eating behaviour and I explored various behaviour change models: "*Intervention designed method described using the Behaviour Change Wheel (BCW) has 3 tasks: 1) understand the behaviour, 2) identify intervention options and 3) identify content and implementation options (Atkins and Michie, 2015). The 4th study being a dissemination piece or case study of actually implementing it in practice. Focus group questions using the COM-B model to identify Capability, Opportunity and Motivation in relation to manipulating carbohydrate intake [Behaviour]* (24th May 2018). discovered that most nutrition interventions were based upon the notion of 'it seemed like a good idea at the time' (ISLAGIATT) and instead wanted to incorporate a more systematic, evidence-based approach in my practice and online nutrition courses to demonstrate the effectiveness of this. To achieve this, I needed a suitable tool that could be used remotely to quickly assess baseline nutrition knowledge and practices that could guide targeted nutrition education, interventions and strategies to optimise dietary intake of endurance athletes in competitive settings.

1.4 Goal of this Professional Doctorate research

The overall goal of the research within this thesis was to investigate whether athletes didn't eat CHO before or during competition because they were *unaware* of the current CHO guidelines, have difficulties with *translating* knowledge into practice, have *personal beliefs* or are exposed to *external factors* which influence their intake during competition. To achieve this, the overall aims of this Professional Doctorate research were to:

1. Develop a reliable and valid, time-efficient tool to objectively assess endurance athlete's knowledge of CHO requirements for competition.
2. Quantify the relationship between endurance athlete's knowledge of CHO requirements and dietary CHO intake before and during competition.
3. Qualitatively assess the reasons underpinning endurance athlete's dietary CHO choices for competition through the lens of behaviour change models.

Chapter 2

Literature review: Carbohydrate nutrition knowledge and practices of endurance athletes within competition

2.1 Introduction

Despite strong scientific evidence and sports nutrition guidelines recommending carbohydrate (CHO) intakes to enhance endurance sports performance, a clear mismatch still exists between current guidelines and practice amongst endurance athletes (Burke et al., 2001; Spronk et al., 2015; Masson and Lamarche, 2016; Heikura et al., 2017b; McLeman, Ratcliffe and Clifford, 2019). This is at odds with the wealth of literature available demonstrating the performance benefits when endurance athletes compete with optimal CHO availability (Burke et al., 2001; Jeukendrup, 2004; Burke et al., 2011; Kerksick et al., 2017; Impey et al., 2018). It is unclear whether athletes fail to achieve current sports nutrition guidelines because they lack knowledge or practical skills to implement them, are unable to translate knowledge into practice or are influenced by external factors within the competition setting.

This review will first provide an outline of the CHO requirements for competition and the observed mismatch between guidelines and practice. Secondly it will outline how knowledge for nutrition is evaluated and what tools exist to specifically assess knowledge of CHO for competition. Finally, it will describe our current understanding of factors influencing dietary behaviour that may ultimately influence the mismatch observed in practice as assessed through the lens of the COM-B behaviour change model. The gaps identified will provide a background for the key questions addressed on the chapters of this thesis.

2.2 Mismatch between carbohydrate guidelines for competition and practices of endurance athletes

This section provides a detailed overview of the literature demonstrating a mismatch between CHO guidelines and dietary practices of endurance athletes within competitive settings. To more easily evaluate the mismatch between guidelines and practice, the nutrition guidelines have been re-classified in four different categories — based on their timing — when CHO can optimise performance namely: *CHO loading* intake consumed 24 - 48 h prior to competition, a *pre-event CHO* meal consumed 1 - 4 h prior to competition, *during competition CHO* intake and *post-competition CHO* intake for rapid recovery (Kerksick et al., 2008; Jeukendrup, 2014; Thomas, Erdman and Burke, 2016b; Kerksick et al., 2017; Burke et al., 2019). For optimal performance at these time points, these current guidelines recommend —as a general rule— that endurance athletes should consume:

- 8 - 12 g•kg^{-1} CHO 24 - 48 hours prior to their event when *CHO loading* (specifically for events ≥ 90 min in duration),
- 1 - 4 g•kg^{-1} CHO in the *pre-event meal* consumed 1 - 4 hours before competition,
- 60 - 90 g•h^{-1} *CHO during* events over 1.5 hours in duration, and
- 1.0 - 1.2 g•kg•h^{-1} CHO *post-exercise* to enhance glycogen resynthesis for rapid recovery.

As the aim of this research was to explore the relationship between knowledge and practice of current CHO guidelines, the research incorporated within this review assesses knowledge and dietary intakes of endurance athletes recorded during real-world competition since first publication of current CHO guidelines (Kerksick et al., 2008). Sports focused upon athletes competing in all free-living amateur and professional road cycling (single and multi-stage road cycling), marathon running marathon and triathlon (70.3 half-Ironman® and Ironman®) competitive events of greater than 2.5 h and less than < 18 h in duration (the maximum time allowable to complete an Ironman®). Nutritional requirements and practices of athletes competing in ultra-endurance events of greater duration are likely to differ with greater relying upon fat oxidation than CHO and were thus not incorporated within this review (Nikolaidis et al., 2018). Of the 57 studies originally identified reporting CHO intake of endurance athletes, those that recorded dietary intake during training, provided nutrition intervention or education were excluded. While the guidelines are clear, concise and supported by ample research, available literature shows a clear mismatch between these consensus guidelines and current practice in most of these categories.

2.2.1 Carbohydrate loading intakes of endurance athletes 24 h prior to competition

The aim of CHO loading is to maximise endogenous glycogen stores prior to endurance competition lasting > 90 min in duration through high CHO availability and tapered training (Bussau et al., 2002; Kerksick et al., 2017). Contemporary CHO loading guidelines recommend endurance athletes consume 8-12 g•kg^{-1} CHO in grams relevant to the body mass of the athlete per day for 24 - 48 hours prior to competition (Kerksick et al., 2008; Thomas, Erdman and Burke, 2016b). It is important to highlight that CHO-loading recommendations and guidelines have changed slightly through time, though a high CHO intake prior to competition has been a consistent message (Karlsson and Saltin, 1971; Sherman et al., 1981; Hawley, 1997; van Loon et al., 2000; Bussau et al., 2002; Kerksick et al., 2008; Jeukendrup, 2014; Kerksick et al., 2017). From 15 studies originally identified, a summary of the current literature investigating free-living CHO intakes consumed 24 h prior to long duration (> 2.5 h and < 18 h) cycling, triathlon and running since 2008 is portrayed in **Table 1.**

It is noteworthy from this table that typical CHO loading intake of endurance athletes prior to competition is 3.3 - 5.8 g•kg^{-1} (n = 7 studies; 48 – 257 participants), with just one study showing higher intakes of 7.3 ±2.5 g•kg^{-1} for Ironman® triathletes (Masson and Lamarche, 2016) but still not matching the CHO guidelines. There does not seem to have been much change in CHO loading practices prior to real world competition in endurance athletes since the 80's. Suboptimal CHO loading intakes in free-living athletes without supervision or specific instructions were first identified in amateur marathon runners 35 years ago (Burke and Read, 1987). Athletes who reported to be following a CHO loading diet consumed an average 469 g CHO per day (Burke and Read, 1987) which was reported inadequate to meet guidelines at that time when recommendations were made as percentages of total energy. While weight was not reported in that study, little appears to have changed since, with marathon runners recently recorded CHO loading intakes of 262 g (range 2.5 - 3.8 g•kg^{-1}) which remain considerably lower than recommendations (Pugh et al., 2018; McLeman, Ratcliffe and Clifford, 2019). Low CHO loading intakes ranging from 3.5 - 7.3 g•kg^{-1} are also evident within amateur cyclists and multisport athletes (Havemann and Goedecke, 2008; Armstrong et al., 2012; Masson and Lamarche, 2016). Female endurance athletes in particular appear to consume lower absolute (236 - 248 g) and relative (3.5 - 4.8 g•kg^{-1}) CHO intakes the day prior to competition than their male counterparts (Armstrong et al., 2012; Wardenaar et al., 2019).

No studies could be identified detailing the CHO intake of professional endurance athletes in the 24 h period prior to competition since current CHO guidelines were first published in 2008. Professional athletes appear more likely to consume CHO in alignment to guidelines within both one-day or multi-day competitions with CHO intakes exceeding 800g (10.7-12.9g.kg) (García-Rovés et al., 2000; Martin et al., 2002; Rehrer et al., 2010; Heikura et al., 2019)

(Garcia-Roves et al., 1998). However, as these intakes included CHO consumed during competition, were averages of multiple days of competition and did not exclusively record CHO consumed the day prior to competition, total intakes may appear greater than true consumption 24 h prior, so were not included within **Table 1**. Indeed, a highlighted shortcoming of nutritional research in professional cyclists is that data is typically reported as averages which fails to demonstrate daily variation between stages with differing nutritional requirements (Heikura et al., 2019).

As observed in **Table 1**, no endurance athletes seem to consistently achieve CHO loading guidelines in the absence of explicit guidance or directions. Indeed, for 5 out of 7 studies, CHO intake 24 h prior to competition was less than the 5 - 7 $g{\bullet}kg^{-1}$ recommended for daily training (Burke et al., 2001). Professional athletes and Ironman distance triathletes appear more likely to consume greater CHO loading intakes than amateur athletes or those competing in shorter distances. However, whether this is due to athletes' poor knowledge of the guidelines or other factors, is unknown.

Table 1. Carbohydrate loading intakes of endurance athletes 24 h prior to endurance competition

Study	n	Gender	BM (kg)	Competition level	Sport event	CHO g	CHO g•kg^{-1}	CHO % TE	CHO Guideline 8 – 12 g•kg^{-1}
(Armstrong et al., 2012)	42	M	86	Amateur	Cycling 164km road race	368 ±130	4.3†	57	NO
	6	F	67	Amateur		236 ±112	3.5†	49	NO
(Atkinson et al., 2011)	257	NS	71	Amateur	Running London marathon	-	5.0 ±1.9	-	NO
(Havemann and Goedecke, 2008).	45	M	76	Amateur	210km cycling race	-	5.6 ±1.7	54	NO
(Masson and Lamarche, 2016)	84/32	M/F	NS	Age group	Winter Triathletes	365 ±112	5.5 ±1.5	54	NO
					Ironman® 70.3	390 ±160	5.5 ±1.7	54	NO
					World Championship Ironman® 70.3	381 ±159	5.8 ±2.5	48	NO
					Ironman®	529 ±177	7.3 ±2.5	58	NO
(McLeman, Ratcliffe and Clifford, 2019)	43	M	74	Amateur	Running (Event NS)	-	3.3 ±1.7	-	NO
	57	F	59						
(Pugh et al., 2018)	70	NS	70	Amateur	Running Liverpool Marathon	262 ± 93	3.8 ±1.4	-	NO
	30	NS	66		Running Dublin marathon	262 ±120	3.4 ±2.5		NO
(Wardenaar et al., 2019)	54	M	72	Amateur	60km and 120km ultra marathon	327 ±89	4.4 ±1.3		NO
	14	F				258 ±78	4.5 ±1.3		NO

Carbohydrate intakes of endurance athletes competing in cycling, running, triathlon events of 2.5 – 18 h duration recorded in the 24 h period prior to competition since publication of current CHO guidelines (Kerksick et al., 2008). No studies could be identified since 2008 with intakes of professional athletes in the 24 h period prior to competition that did not also include CHO consumed during competition. NS not specified, M male, F female, BM body mass, †estimated from BM and absolute CHO intake, %TE Percentage total energy from carbohydrates

2.2.2 Carbohydrate intakes of endurance athletes in the pre-event meal

The aim of a pre-event meal consumed is to replace or maintain liver glycogen stores by consuming a high CHO meal or snack 1 – 4 hours prior to competition (Kerksick et al., 2017). Contemporary CHO guidelines recommend the meal consumed prior to competition contains 1 - 4 g•kg^{-1} CHO (Kerksick et al., 2008; Thomas, Erdman and Burke, 2016a). Of 11 studies originally identified reporting CHO intakes consumed within the pre-event meal before cycling, triathlon and running events of between 2.5 h and 18 h duration, 7 were found to record free-living practices of endurance athletes without education or intervention.

As demonstrated in **Table 2**, pre-competition CHO guidelines are frequently achieved by endurance athletes with CHO intakes of 1.0 - 3.4 g•kg^{-1} recorded by amateur and elite runners, triathletes and cyclists (Havemann and Goedecke, 2008; Cox, Snow and Burke, 2010; Heikura et al., 2019; McLeman, Ratcliffe and Clifford, 2019). To date, just one study showed pre-event CHO intakes of 0.8 g•kg^{-1} in amateur marathon runners failing to achieve minimum guidelines (Pugh, Kirk et al. 2018). The literature published in free-living athletes to date suggesting that amateur, professional, male and female endurance athletes typically meet the minimum pre-competition meal CHO recommendations.

Table 2: Carbohydrate intakes in the pre-competition meal consumed by endurance athletes 1 - 4 h prior to competition

Study	n	Gender	BM (kg)	Competition level	Sport and event	CHO intake g	CHO intake $g \cdot kg^{-1}$	CHO intake Guideline 1 - 4 $g \cdot kg^{-1}$
(Atkinson et al., 2011)	257	NS	71	Amateur	Running London marathon	-	1.7 ±0.8	YES
(Cox, Snow and Burke, 2010)	36	M	69	National	Triathlon (Olympic) senior and <23 Australian	198 ±81	2.9 ±1.2	YES
	15	F	59			195 ±52	3.3 ±0.8	YES
(Garcia-Roves et al., 1998)	10	M	67	Professional	Road cycling *grand tour* Vuelta España	298 ±53	4.5 ±0.7	YES
(Havemann and Goedecke, 2008)	45	M	76	Amateur	Road cycling 210km race, South Africa	76 ±32	1.0 ±0.4	YES
(Heikura et al., 2019)	6	M	77	Professional	Cycling. Classics Belgium	-	1.1 ±0.2	YES
(McLeman, Ratcliffe and Clifford, 2019)	43	M	74	Amateur	UK runners	-	1.2 ±0.6	YES
	57	F	59			-		
(Pugh et al., 2018)	70	NS	70	Amateur	Running Liverpool marathon	76 ±45	1.1 ±0.9	YES
	30	NS	66	Amateur	Running Dublin marathon	59 ±41	0.8 ±0.8	NO
(Wardenaar et al., 2015)	54	M	72	Amateur	Running 60km ultra marathon	102 ±49	-	YES
	14	F						

Carbohydrate intakes of endurance athletes competing in cycling, running, triathlon events of 2.5 – 18 h duration recorded in the pre-competition meal since publication of current CHO guidelines (Kerksick et al., 2008). As few contemporary studies in professional athletes could be identified, older studies with CHO intakes of professional athletes incorporated for reference. NS not specified, M male, F female, BM body mass,

2.2.3 Carbohydrate intakes of endurance athletes during competition

Consuming CHO during exercise can increase exercise capacity and improve performance by maintaining high rates of CHO oxidation (Jeukendrup, 2014). Contemporary CHO intake guidelines during competition depend on the intensity and duration of the exercise, whereby endurance athletes are recommended to consume 60 - 90 $g{\bullet}h^{-1}$ when competing in events for > 2.5 hours (Kerksick et al., 2008; Jeukendrup, 2014; Thomas, Erdman and Burke, 2016b). As demonstrated in **Table 3**, CHO intake during competition varies greatly between endurance athletes competing in different sports, distances and athlete level with mean CHO intakes of 12 - 94 $g{\bullet}h^{-1}$. Indeed, athletes in only 6 out of 17 studies were found to achieve recommended intakes of 60 - 90 $g{\bullet}h^{-1}$ CHO during competition.

Professional athletes appear more likely to achieve recommended intakes during competition which may be due to greater levels of support and provision of CHO foods by team, support riders or vehicles than available to amateur athletes (Burke, 2001; Ebert et al., 2007). Similarly, cyclists and triathletes seem more likely to meet recommendations than runners, with higher amounts of CHO consumed during the cycling leg than when running (Kimber et al., 2002; Pfeiffer et al., 2012). This may relate to a greater incidence of gastrointestinal symptoms observed during running events resulting in runners intentionally under-consuming CHO to manage symptoms (Pugh et al., 2018). As observed in **Table 3**, marathon runners frequently record CHO intakes well below those recommended (Martinez et al., 2018; Pugh et al., 2018; Hoogervorst et al., 2019). Indeed, just 6.6% of marathon runners consumed 60 $g{\bullet}h^{-1}$, with 52% failing to achieve the minimum recommendations of 30 $g{\bullet}h^{-1}$ (Martinez et al., 2018). Only when marathon runners were provided with a scientific plan did they meet CHO recommendations, consuming considerably more (65 $g{\bullet}h^{-1}$ vs 38 $g{\bullet}h^{-1}$) those without explicit nutritional guidance (Hansen et al., 2014). These findings suggest that knowledge and a specific nutritional plan may be important for endurance athletes to achieve optimal CHO during competition, however the reasons behind poor compliance with guidelines in these studies, is unknown.

Table 3. Carbohydrate intakes of endurance athletes consumed per hour during competition

Study	n	Gender	BM	Competition level	Sport event	Average Finish time (h:m)	CHO intake g•h^{-1}	CHO intake Meets Guideline 60 - 90 g•h^{-1}
(Armstrong et al., 2012)	42	M	86	Amateur	Cycling 164km road race	9:10	12†	NO
	6	F	67	Amateur		9:00	13†	NO
(Atkinson et al., 2011)	257	NS	71	Amateur	Running Marathon London	4:30	23 ±15	NO
(Black, Skidmore and Brown, 2012)	16/2	M/F	79	Amateur	Cycling K4 cycle 384km New Zealand	16:21	52 ±27	NO
(Cox, Snow and Burke, 2010)	36	M	69	Elite	Triathlon Olympic Triathletes senior and <23 Australian	1:57	25†	NO
	15	F	59			2:08	23†	NO
(Ebert et al., 2007)	8	M8	71	National	Cycling Australian Tour Down Under	2:55	48 ±19	NO
	26	F	63	International	Cycling road Tour De L'Aude	2:46	21 ±10	NO
(Hansen et al., 2014)	11/3	M/F	77	Amateur	Copenhagen Marathon 2013	3:49	38 ±18	NO
(Garcia-Roves et al., 1998)	10	M	67	Professional	Road Cycling *grand tour* Vuelta España	NS	25†	NO
(Havemann and Goedecke, 2008)	45	M	76	Amateur	Cycling 210km	3:14	63 ±23	**YES**
(Heikura et al., 2019)	6	M	77	Professional	Classics cyclists Belgium	NS	51 ±9	NO
(Hoogervorst et al., 2019)	75/23	M/F	73	Amateur	Running Marathon,	4:16	41†	NO
	36/7	M/F	74		Running 60km	5:50	52†	NO
	8	M	71		Running 120km	12:30	37†	NO
(Kimber et al., 2002)	10	M	74	Amateur	Ironman® Triathletes	12:00	81†	**YES**
	8	F	62	Amateur		12:36	62†	**YES**
(Martinez et al., 2018)	41/12	M/F	68	Amateur	Running Mallorca 44km marathon	NS	33 ±14	NO
(Muros et al., 2019)	9	M	69	Professional	Cycling Vuelta Espana 2015	NS	91 ±15	**YES**
(Pfeiffer et al., 2012)	34/19	M/F	67	Amateur & Professional	Triathlon Ironman® Hawaii	11:40	62 ±26	**YES**
	45/9	M/F	73	Amateur & Professional	Triathlon Ironman® Germany	11:09	71 ±25	**YES**
	36/7	M/F	75	Amateur & Professional	Triathlon half Ironman® (70.3)	6:05	65 ±25	**YES**

	22/6	M/F	71	Amateur	Running Marathon Germany	3:46	35 ±26	NO
	28	M	81	Amateur	Road Cycling	3:32	53 ±22	NO
	7	M	70	Professional	Road cycling Dauphine Libere	5:04	64 ± 20	**YES**
	8	M	71	Professional	Road cycling Vuelta de Espana	5:22		
(Pugh et al., 2018)	70	ns	70	Amateur	Running Liverpool marathon	4:20	24 ±12	NO
	30	ns	66		Running Dublin marathon	3:56	24 ±18	NO
(Ross et al., 2014)	5	M	72	National	Road Cycling Tour of Gippsland	NS	41 ±24	NO
	5	M		International	Road Cycling Tour of Geelong	NS	64 ±24	**YES**
(Saris et al., 1983)	4	M	69	Professional	Road Cycling Tour de France	NS	94†	**YES**

Carbohydrate intakes of endurance athletes competing in cycling, running, triathlon events of 2.5 – 18 h duration recorded during competition since publication of current CHO guidelines (Kerksick et al., 2008).

NS = not specified, † = Hourly intake not reported and estimated absolute CHO intake and mean duration

2.2.4 Carbohydrate intakes of endurance athletes' post-event for rapid recovery

The purpose of CHO consumed in the hours following exercise is to support rapid recovery of glycogen levels (Thomas, Erdman and Burke, 2016a). Current recommendations for rapid glycogen restoration following exercise are for athletes to consume 1.0 - 1.2 $g{\bullet}kg{\bullet}h^{-1}$ CHO for up to 4 hours post exercise (Thomas, Erdman and Burke, 2016a). As observed in **Table 4,** surprisingly few studies (n = 5) have quantified current CHO intakes of athletes in the recovery period after free-living cycling, triathlon or running competition, most of which indicate that many athletes meet recommendations.

Two additional studies exploring recovery CHO intakes after training also suggest that with CHO intakes ranging between 0.9 – 1.3 $g{\bullet}kg^{-1}$, amateur and national level runners typically achieve CHO guidelines after training (Heikura et al., 2017a; McLeman, Ratcliffe and Clifford, 2019). Masters triathletes were found to be less likely to meet recommendations than younger triathletes consuming 0.7 vs 1.1 $g{\bullet}kg^{-1}$ post-exercise, although they were more likely to consume this within 30 minutes vs 60 minutes which may support more rapid glycogen restoration (Doering et al., 2016). While professional cyclists racing multi-day stage races such as the Tour of Andalucia (Sanchez-Munoz, Zabala and Muros, 2016) and Vuelta D'Espana consumed optimal CHO for rapid recovery (Garcia-Roves et al., 1998; Muros et al., 2019), one day Classic race cyclists did not, as they intentionally chose to consume less CHO following certain stages in consideration of an upcoming rest day (Heikura et al., 2019). As aggressive CHO re-feeding post-exercise is most relevant for repeated exercise separated by 24 h, achievement of CHO guidelines may be more relevant to athletes competing in events with multiple-day competitions versus those competing in single-day events with days or weeks of separation between.

Although the literature is sparse regarding post-competition CHO intakes of endurance athletes following free-living cycling, triathlon or running events, that available suggests that the majority of amateur and professional amateurs may consume CHO in alignment with guidelines.

Table 4. Carbohydrate intakes of endurance athletes post competition or intensive training for rapid recovery

Study	n	Gender	bm (kg)	Competition level	Sport Event	CHO		
						g	g•kg^{-1}	Guideline 1.0 - 1.2 g•kg^{-1}
(Doering et al., 2016)	17/10	M/F	73	Amateur	Triathlon Masters: >50y	-	0.7 ±0.4	NO
	3/12	M/F	64		Triathlon <30y	-	1.1 ±0.6	YES
(Garcia-Roves et al., 1998)	10	M	67	Professional	Road Cycling *grand tour* Vuelta España	134 ±29	2.0 ± 0.5	YES
(Heikura et al., 2019)	6	M	77	Professional	Road Cycling. Classics Belgium (1 day)	-	0.5 ±0.2	NO
(Muros et al., 2019)	9	M	69	Professional	Road Cycling Tour of Spain 2015	147 ±33 (2h)	1.1†	YES
(Sanchez-Munoz, Zabala and Muros, 2016)	6	M	68	Professional	Road Cycling Tour of Andalucia 4-day stage	74 ±20	1.1†	YES

Carbohydrate intakes of endurance athletes competing in cycling, running, triathlon events of 2.5 – 18 h duration recorded post-competition since publication of current CHO guidelines (Kerksick et al., 2008). Studies reporting recovery CHO intakes post training were excluded. As few contemporary studies in professional athletes could be identified, older studies with CHO intakes of professional athletes incorporated for reference. M = male, F = female, bm = body mass, n = number of athletes, †estimated from recorded absolute CHO intake and bm

2.3 Nutrition knowledge of endurance athletes

The mismatch between guidelines and practice as evidenced in the previous sections suggest that a lack of knowledge may explain these observations. Therefore, determining athletes' knowledge of CHO guidelines is important to understand and address this mismatch. Of 58 questionnaires originally identified assessing nutrition knowledge of athletes, those suitable for endurance athletes assessed either general nutrition knowledge (Rash et al., 2008; Spendlove et al., 2011; Sedek and Yun Yih, 2014; Devlin and Belski, 2015; Devlin et al., 2017) or sports specific nutrition knowledge (Blennerhassett et al., 2018; Sparks et al., 2018; Trakman et al., 2018; Trakman et al., 2019a; Trakman et al., 2019b; Rothschild, Kilding and Plews, 2020b; Tam et al., 2020). These questionnaires demonstrate that athletes achieve general and sports nutrition knowledge scores ranging between 33 – 78% (Heaney et al., 2011; Trakman et al., 2016; Tam et al., 2019). However, these questionnaires assessing nutritional knowledge are very different in nature, ranging from 11 to 76 questions per questionnaire and have also been conducted in a heterogenous athlete population, making difficult to draw conclusions in relation to specific athletes' knowledge. The most appropriate questionnaire to assess knowledge must suit the population being considered and be capable of identifying which particular nutrition concepts are not well understood (Trakman et al., 2016). However, no knowledge questionnaire to assess endurance athletes understanding based on current CHO recommendations was identified.

2.3.2 Carbohydrate specific nutrition knowledge in endurance athletes

To date there is no specific nutrition knowledge questionnaire that focuses exclusively on endurance athletes during competition to optimise performance based on current guidelines. As summarised in **Table 5,** just 7 existing sports nutrition knowledge tools assess elements of CHO knowledge containing between 1 - 10 general or specific CHO questions relevant to endurance athletes and competition. An additional 4 studies explored factors influencing competition food choice, CHO periodisation or practice within competition and contained CHO specific questions (Heikura, Stellingwerff and Burke, 2018; Blennerhassett, McNaughton and Sparks, 2019; Parnell et al., 2019; Rothschild, Kilding and Plews, 2020a). The questions used in these studies to assess CHO knowledge and practice include a variety of true or false statements, definitions of glycaemic index, multiple choice questions to identify CHO food sources or specify amounts of CHO at certain time points during competition as detailed in **Table 6**.

Indeed, only 2 published nutrition knowledge questionnaires report CHO knowledge with a distinct subsection score, neither of which are conclusive or ask questions in alignment with current CHO recommendations for endurance athletes (Furber, Roberts and Roberts, 2017; Karpinski, Dolins and Bachman, 2019). While Furber, Roberts and Roberts (2017) contained the most CHO questions (n = 15) and was validated to assess knowledge in track and field athletes, questions were not in alignment with current CHO guidelines. As a demonstrative example of outdated questions **(Table 6)**, Furber, Roberts and Roberts (2017) asked "*When CHO loading, which percentage of your diet should come from CHO*?" when CHO loading recommendations should be provided in grams relative to body mass of the athlete (Burke et al., 2001). Findings from existing nutrition knowledge research suggest that endurance athletes may possess inadequate knowledge of contemporary CHO guidelines for competition, but despite its importance, core knowledge in this area is scattered in different questionnaires rather than in a single knowledge assessment tool.

Table 5. Nutrition knowledge questionnaires that contain elements relating to carbohydrate for competition

Study	Population (n)	Validated	Question type	Questions (n)	General Knowledge score Mean ±SD (maximum)	CHO Questions			
						(n)	Subsection score Mean ±SD (maximum)	CHO topic	Assess knowledge of current CHO guidelines
(Blennerhassett et al., 2018)	EA (101)	Yes	MCQ, TF	76	68 ±9.5 (100)	5	NA	C1, C2	No
(Doering et al., 2016)	EA (182)	Yes	MCQ	NS	NA	1	NA	C5	Yes
(Furber, Roberts and Roberts, 2017)	EA (58)	Yes	MCQ, TF	62	89 ±16 (145)	15	13.6 ±2.3 (23)	C1, C2, C3, C5,	No
(Karpinski, Dolins and Bachman, 2019)	EA (202)	Yes	MCQ, TF	49	15.9 ±9.2 (49)	9	3.3 ±3.0 (11)	C1, C2, C4, C5	Yes
(McLeman, Ratcliffe and Clifford, 2019)	EA (100)	No	MCQ	NS	NA	3	NA	C2, C3, C5	Yes
(Sparks et al., 2018)	EA (2550)	No	MCQ, FCQ	NS	NA	6	NA	C2, C3, C4, C5	Yes
(Trakman et al., 2019a)	GA (177)	Yes	MCQ	89/37	47.0 ±13 (100)	2	NA	C5	No

Existing nutrition knowledge questionnaires include a variety of questions, scores and topics and do or don't align with current CHO guidelines. Whereby EA = endurance athlete, GA = general athlete, N.A = not applicable, N.S = Not specified CSQ = carbohydrate specific questions GNQ = general nutrition question, FCQ = Food Choice Questionnaire, TF = True False questions, MCQ = Multiple choice questions, C1 = General CHO Questions; C2 = CHO Loading Questions; C3 = CHO pre-event meal questions; C4 = CHO during competition questions; C5 = CHO recovery questions

Table 6. Questions asked in existing nutrition knowledge research relating to carbohydrate for competition

Reference	CHO Questions
(Blennerhassett et al., 2018)	Which of the following foods are high in CHO? Which of these statements is the most accurate definition of the term 'Glycaemic Index'? For optimum hydration, the % of CHO in a sports drink should be: To replace energy stores, the most important nutrient to replace after a 1-h run is: Which one of the following set of 2 snacks would be most effective at replacing CHO stores?
(Blennerhassett, McNaughton and Sparks, 2019)	Habitual and competition dietary restrictions and manipulation
(Doering et al., 2016)	Identify how many grams of CHO in $g.kg^{-1}$ should consume post exercise to optimise recovery?
(Furber, Roberts and Roberts, 2017)	In general what % of your diet should be made up from CHO? What best describes the glycaemic index? When CHO loading, which percentage of your diet should come from CHO? A high CHO meal 2-4 hours pre-exercise can lead to improvements in endurance performance? Which meal would be recommended to eat 3hours before training? Which would be the best item to snack in the 3 minutes pre-exercise? Is it always beneficial to have an isotonic sports drink in the 60 minutes pre-event? A high CHO diet helps to reduce protein breakdown in the body? If competing twice in one day, morning & evening, when is the optimum time to eat after the first event? Is it more important to replace CHO protein or fat after the first event? Immediately post exercise is it best to consume high or low glycaemic index CHO to support muscle glycogen recovery? Are these foods high or low in CHO (pasta/weetbix/bread/jellybabies)? Are these foods high or low in glycaemic index? How much CHO is in an isotonic sports drink? Which drinks are isotonic? Which drink contains the highest amount of CHO?

(Heikura, Stellingwerff and Burke, 2018)	Understanding of CHO periodization during training Do you follow a specific diet plan in the 24 - 48 hour before the race day? Do you pay more attention to adequate fueling in the 1 - 4h before key sessions? Do you focus on fueling before more during competition periods? Do you follow a specific diet plan during the race? Do you consume CHO during workouts? (I find it helps me to practice for race fuelling nutrition strategies) Do you pay more attention to adequate recovery within 3 hours after key sessions? Do you focus on recovery eating after key training sessions more during competition periods?
(Karpinski, Dolins and Bachman, 2019)	Eating a low carbohydrate diet will reduce muscle carbohydrate stores (glycogen) which can cause early fatigue A high carbohydrate diet helps athletes reduce muscle protein breakdown in the body. An athlete's plate should consist of more carbohydrate-rich foods than protein foods. Glycogen (carbohydrate stores) is the muscle's main fuel for high intensity exercise such as sprinting. An endurance athlete does not need to eat a high carbohydrate diet during training as long as they load up on carbohydrate prior to competition.
(McLeman, Ratcliffe and Clifford, 2019)	Select recommended intakes for effective CHO loading 24 hour before a race Select recommended intakes for CHO 1 - 4 hour before a race Select recommended CHO intake post-race An endurance athlete such as a marathon runner, distance cyclist or Ironman® distance triathlete should consume 60 - 90 grams of carbohydrate hourly during training/competition. Swishing a sports drink or gel in the mouth without swallowing it during endurance exercise may reduce fatigue. Both carbohydrate and protein foods should be consumed after exercise to enhance recovery. The best time to eat carbohydrate to restore glycogen (carbohydrate) muscle stores is 4 hours after exercise.
(Nichols et al., 2005)	When exercising >1 hour, an athlete should drink sports drinks rather than water Sports drinks are better than water because they restore glycogen in the muscles Athletes should drink sports drink within 2 hours after exercise

(Parnell et al., 2019)	When racing, are there any types of food or fluid that you avoid in your pre-race meal or snack 0-4 hours prior to running races/competition? When racing, please describe what you would typically choose to eat/drink (including supplements/special products) within 4 hours before running What are your reasons for avoiding certain foods/fluids before race/competition?
(Rothschild, Kilding and Plews, 2020a)	Periodising CHO intake by duration/intensity/type/timing/sport Frequency eating CHO before AM workouts Does your breakfast vary based on duration/intensity/type/sport?
(Sparks et al., 2018)	CHO loading and CHO use, type of CHO used loading. CHO loading to 8-12 g.kg.bm.d Type of CHO used before event Type of CHO used during event, amount of CHO in sports drink (%) Type of CHO used after event If CHO requirements were calculated or guessed. Reasons why CHO load/not use CHO before/during after
(Trakman et al., 2019a) (Trakman et al., 2017)	Which of these foods would provide enough CHO for recovery from about 1h of high intensity aerobic exercise? CHO requirements based as requirements in g.kg.d with specified type (endurance) and intensity) moderate to high)

Existing nutrition knowledge questions and research exploring practices in training and competition, include a variety of multiple choice, true or false, short answer questions relating to CHO for competition.

2.3.3 Endurance athlete knowledge of current carbohydrate guidelines

As observed in **Table 5,** while 7 existing nutrition questionnaires assess elements of CHO specific nutrition knowledge of endurance athletes, just 4 contain questions in alignment with current recommendations. Furthermore, only 3 questionnaires explicitly assess endurance athletes' knowledge of current CHO guidelines relevant to competition (Doering et al., 2016; Sparks et al., 2018; McLeman, Ratcliffe and Clifford, 2019). Specific questions in existing questionnaires or studies assessing practice in relation to current CHO guidelines (**Table 6**) found that just 4% of amateur runners could correctly identify the amount of CHO required for CHO loading, with 11% choosing incorrectly and the majority (85%) selecting '*I don't know*' (McLeman, Ratcliffe and Clifford, 2019). Likewise, knowledge of CHO guidelines and practices for optimal recovery appears to be poor in endurance athletes with only 25% of triathletes correctly identifying the recommended amount of CHO to consume post exercise for optimal recovery and 43% choosing '*I don't know'* (Doering et al., 2016). Poor knowledge of CHO for rapid recovery was also observed in amateur runners, where only 1% were able to identify the correct amount of CHO to consume and the remainder selecting '*I don't know'* or answering incorrectly (McLeman, Ratcliffe and Clifford, 2019). These findings highlight potential gaps in knowledge of CHO for competition which may partially explain the mismatch observed in practice. However, there are currently no questionnaires to rapidly assess endurance athletes' knowledge of contemporary CHO recommendations to clarify this and guide future education or nutrition intervention.

2.4 Factors influencing translation of carbohydrate nutrition knowledge into practice according to the COM-B model of behaviour change

The link between general nutrition knowledge and dietary behaviour is complex, influenced by a variety of factors including taste, food preference, cultural, beliefs, convenience, skills in shopping or food preparation (Burke, 2001; Heaney et al., 2011; Trakman et al., 2016). Increased nutrition knowledge may not translate to superior dietary changes, with studies showing that many athletes do not apply what they know (Heaney et al., 2008; Spronk et al., 2015; Heikura et al., 2017b). To translate knowledge into practice, the athlete must be ready for change, want to change and be able to change their dietary intake (Bartlett and Drust, 2020). When mapped to the constraints of the Theoretical Domains Framework (TDF), the COM-B theoretical model of behaviour change (**Figure 2**) suggests that in order for an athlete to engage in the targeted Behaviour; i.e. to consume CHO before, during and after competition in alignment with recommended guidelines, they must have the psychological and physical Capability (knowledge and skills), the social and physical Opportunity and Motivation to consume that CHO in the presence of competing behaviours (Michie, van Stralen and West, 2011; Bentley et al., 2021). The COM-B model thus provides a suitable framework to understand factors influencing dietary choices of endurance athletes within competition and identify suitable interventions or behaviour change techniques that address and enable dietary changes (Michie, van Stralen and West, 2011; Michie et al., 2013).

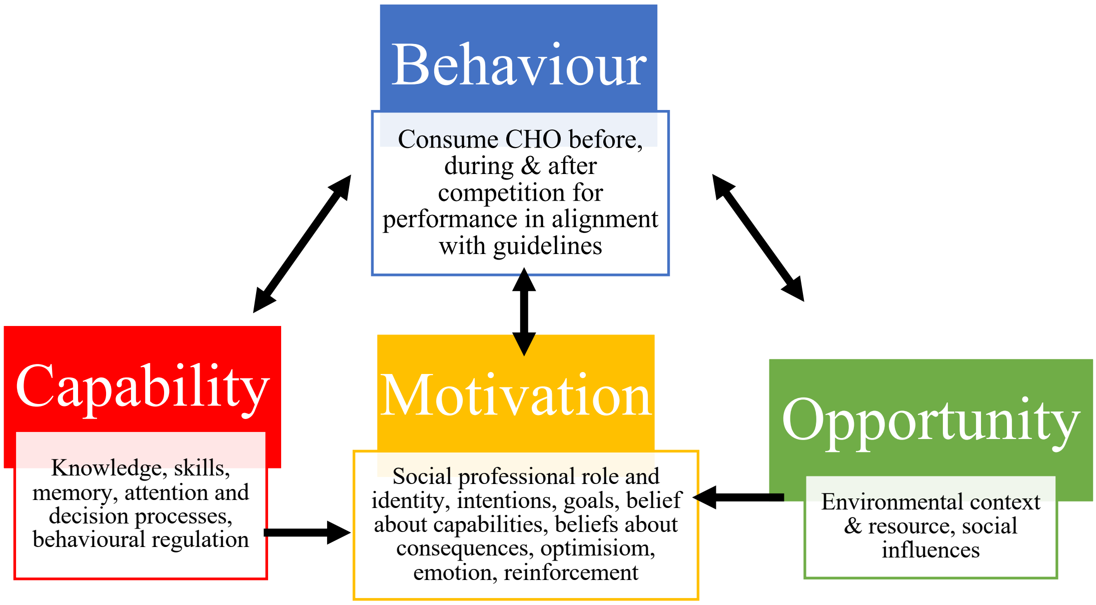


Figure 2. The COM-B model of behaviour change mapped to the theoretical constraints of the TDF

Capability, Opportunity and Motivation to change Behaviour model according to the Theoretical Domains Framework (Michie, van Stralen and West, 2011; Bentley et al., 2021)

2.4.2 Capability of athletes to consume carbohydrate in alignment with guidelines

To be capable of consuming CHO within competition in alignment with recommended guidelines, athletes must have sufficient knowledge and skills, memory, attention, decision processes and behavioural regulation to do so (Michie, van Stralen and West, 2011; Bentley et al., 2021). Practical challenges with CHO loading in free-living athletes were first identified over 30 years ago with marathon runners who believed they were CHO loading failed to meet minimum recommended CHO intakes prior to a marathon (Burke and Read, 1987). Athletes may believe they are CHO loading in alignment with guidelines, however their actual intake may fail to reach these targets when measured quantitatively (Havemann and Goedecke, 2008; Atkinson et al., 2011; Wilson, 2016). A discrepancy appears to exist between an athlete's perception of a CHO loading diet and knowledge of the intake required to achieve this (Atkinson et al., 2011) which may be influenced by an athlete's poor food composition knowledge, inadequate CHO in their habitual diet or personal beliefs (Burke, 2001; Rothschild, Kilding and Plews, 2020a). Similarly, athletes may intentionally restrict food intake, have gastrointestinal challenges, be influenced by popular fad diets, a chaotic lifestyle or find that constant travel between races limits their ability to plan and consume CHO in alignment with guidelines (Burke, 2001).

2.4.3 Opportunity for athletes to consume carbohydrate in alignment with guidelines

The opportunity for athletes to consume CHO in alignment with current guidelines is impacted by environmental context, resources and social influences (Michie, van Stralen and West, 2011; Bentley et al., 2021). The unique dynamics of a sport and team culture, role within a team and race position including racing in a breakaway, varying intensity, aggressive race tactics may strongly influence access and CHO consumption (Ebert et al., 2007; Heikura et al., 2019). Inadequate CHO intake during races could also result from changing environmental terrain and steep descents hindering consumption (Burke, 2001) and sport-specific regulations dictating when athletes are allowed to consume or collect food and fluids mid-race, access feed station. External provision of food by race organisers or team, support riders or vehicles could influence the opportunity to consume adequate CHO during competition (Burke, 2001; Ebert et al., 2007).

Likewise, environmental factors regarding wind, rain and temperature experienced on the day of competition could play a key role in nutritional adherence as demonstrated by triathletes who consumed more CHO (53 vs 41 $g \cdot h^{-1}$) in warm than in mild weather races (Cox, Snow and Burke, 2010) and cyclists who consumed greater amounts of solid foods on cooler days than when racing in warmer weather (Ebert et al., 2007). Although most research indicates athletes consume adequate CHO in the meal before competition, the starting time of an event could influence intake due to the impact on sleep, eating opportunities and suitable digestion time to avoid GI distress. Indeed, elite Olympic distance athletes consumed 24% more CHO before a race starting in 1PM in the afternoon than at 11AM in the morning (Cox, Snow and Burke, 2010). Athletes competing in events that begin early morning (such as Ironman®) may have lower CHO intakes than an athlete racing in the afternoon or evening who has more time and opportunities for intake to align with recommendations.

2.4.4 Motivation for athletes to consume carbohydrate in alignment with guidelines

Athletes must be sufficiently motivated to consume CHO in alignment with current guidelines, in relation to their role and identity, intentions, goals, beliefs about capabilities, beliefs about consequences, emotion and reinforcement (Michie, van Stralen and West, 2011; Bentley et al., 2021). An athlete's personal beliefs regarding CHO and performance may influence their CHO intake during competition. The desire to maintain an ideal physique has been shown to play an important role dictating food choices and CHO intake during competition (Heaney et al., 2011; Thurecht and Pelly, 2019; Thurecht and Pelly, 2020; Bentley et al., 2021). Indeed, runners and cyclists intentionally didn't CHO load prior to competition because they believed they didn't need it or feared gaining weight (Heikura, Stellingwerff and Burke, 2018; Sparks et al., 2018). Considering that diets restricting CHO have become increasingly popular for weight management (Heikura, Stellingwerff and Burke, 2018; Nunes et al., 2018) and 69% of male cyclists believe that achieving the lowest body weight possible was most beneficial for cycling performance (Hoon et al., 2019), certain groups of athletes may be intentionally under-fuelling prior to competition due to these underlying beliefs (Tarnopolsky, Zawada et al. 2001).

The importance of CHO to optimise recovery within competition may also be influenced by the sport culture and need for rapid recovery of the individual event. There may be a greater need to rapidly restore glycogen for multi-day events such as cycling stage races than there is during one-day cycling races, marathons or triathlon events. Interestingly, cyclists competing in one day events intentionally consumed suboptimal CHO post-event in consideration of an upcoming rest day and lower requirement to recover rapidly (Heikura et al., 2019). Athletes competing in multi-day events may have greater motivation to fuel optimally for rapid recovery than athletes competing in one-day events and partially explain mismatch observed within competition.

To what extent, and which factors play a primary influence on the mismatch observed between knowledge and CHO intake in practice within competition is yet to be determined. Having a clear understanding of what endurance athletes currently know about CHO guidelines, how they utilise this knowledge in practice, and what factors influence CHO intake during competition can allow sports dietitians to better facilitate the way in which they educate, translate knowledge and support behaviour change to optimise dietary intake of endurance athletes for competitive performance.

2.5 Conclusions and Gaps for Further Study

Despite the pivotal role of CHO in enhancing endurance sports performance, there exists a clear mismatch between contemporary CHO guidelines and CHO practice within competition, with the vast majority of endurance athletes failing to meet optimal intakes without explicit guidance. Evidence suggests that endurance athletes often achieve pre-event CHO recommendations, but consume inadequate CHO to optimise glycogen loading in the 24-36 h period before competition, inadequate CHO during competition and may fail to consume achieve CHO for rapid recovery. Despite CHO guidelines first being published over a decade ago there is currently no standardised tool to assess knowledge of endurance athletes. Accordingly, it is unknown what is the level of core sports nutrition knowledge for CHO of athletes in the endurance athlete population, and what areas of this knowledge require enhanced education. Moreover, it is currently unknown what link there is between knowledge and practice in endurance athletes. Finally, it is unknown what factors —beyond knowledge— influence intake athletes CHO intake for competition. Therefore, this review identifies key areas of research to improve nutritional practices and highlights an ongoing need for sports dietitians to have the tools to understand these knowledge and intake gaps and systematically provide endurance athletes with nutritional interventions or education on appropriate CHO intakes for optimal performance during competition.

Chapter 3

Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q): validation of a practical and time-efficient tool for knowledge assessment

(Study 1)

Article published in *Sports Sciences for Health*

Sampson, G., Pugh, J.N., Morton, J.P. *et al.* Carbohydrate for endurance athletes in competition questionnaire (CEAC-Q): validation of a practical and time-efficient tool for knowledge assessment. *Sport Sci Health* (2021). https://doi.org/10.1007/s11332-021-00799-8

3.1 Research orientation Study 1

While developing the CEAC-Q, I was working freelance as a sports dietitian and building online sports nutrition courses to educate athletes on training and race nutrition. I sought to develop a tool that could inform my practice and systematically help guide the way I educated my athletes in a way that resulted in dietary behaviour changes. "*I keep coming back to an interest in behaviour change. I'm working in a group setting with cyclists doing workshops and online teaching. Is there a way to research the effectiveness of this model? (17.4.18)*". First it was necessary to assess baseline nutrition knowledge. Having reviewed the literature, I concluded that a nutrition knowledge questionnaire, "*if not sport specific, needs to be sport type specific e.g. endurance athletes. It needs to suit the way they train, fuel. A general nutrition knowledge questionnaire would be reinventing the wheel as there were some good general questionnaires out… focus just on race day sports nutrition, because there is a huge gap in terms of what is being practiced. Despite the guidelines, athletes fail to consume enough before, during and after events. Especially the day before. Why is that? (1.8.2018).*" I identified that there were currently no CHO specific nutrition knowledge questionnaires that could be used by sports dietitians to rapidly assess baseline nutrition knowledge of their athletes and identify knowledge gaps that could explain why athletes fail to consume CHO in practice in alignment with current guidelines.

3.2 Abstract

Purpose: Carbohydrate (CHO) intake is key for endurance performance, but currently there are no practical or time-efficient tools available to assess athletes' knowledge gaps of CHO for competition. This study validated a new practical multiple-choice questionnaire designed to quickly determine endurance athletes core knowledge of CHO intake to maximise endurance performance (CEAC-Q).

Methods: The questionnaire was developed by a group of experts based on the most current scientific evidence. The CEAC-Q consists of 25 questions divided into 5 subsections: CHO metabolism, loading, pre-race meal, during race and recovery with each subsection worth 20 points resulting in a total maximum possible score of 100. A between-groups analysis of variance compared scores in three different population groups to assess construct validity: general population (GenP; n = 67), endurance athletes (EA; n = 145), and registered sports dietitians/nutritionists (SDN; n = 60).

Results: As expected, there was increasing level of knowledge between populations with a significant difference in CEAC-Q total and subsection scores (mean ±SD) observed between all pairwise comparisons; GenP (17 ±20 %, 3 ±5), EA (46 ±19 %, 9 ±5) and SDN (76 ±10 %, p = < 0.001, 15 ±4 %, p < 0.001) respectively. The CEAC-Q took athletes an average 10:36 ±07:45 minutes to complete online.

Conclusion: The CEAC-Q is a new psychometrically valid, practical and time-efficient tool for practitioners to assess athletes' knowledge of CHO for competition in less than 10 minutes, allowing for quick and accurate identification of knowledge gaps to nutrition strategies to optimise performance.

3.3 Introduction

Endurance athletes have been reported to not achieve CHO guidelines for competition despite strong scientific evidence supporting optimal CHO availability to enhance endurance performance (Stellingwerff and Cox, 2014; Spronk et al., 2015; Masson and Lamarche, 2016; Thomas, Erdman and Burke, 2016b; Heikura et al., 2017b; McLeman, Ratcliffe and Clifford, 2019). In addition to laboratory-based research, real-world sports nutrition interventions have demonstrated improved performance in endurance athletes when optimal CHO practices are followed (Hottenrott et al., 2012; Hansen et al., 2014; Mujika, 2018). The mismatch between current guidelines and dietary practice within competition may be lack of knowledge, but this has not been systematically addressed and there is currently no tool to quickly assess this.

By systematically assessing athletes' baseline knowledge of CHO requirements for competition, sports dietitians could better design, facilitate and evaluate targeted nutrition interventions to address knowledge gaps that ultimately optimise competitive performance (Heaney et al., 2011). While questionnaires on general sports nutrition knowledge of athletes are available (Furber, Roberts and Roberts, 2017; Blennerhassett et al., 2018; Karpinski, Dolins and Bachman, 2019; Trakman et al., 2019a), none of them focus exclusively on current CHO guidelines in relation to competition (Thomas, Erdman and Burke, 2016b). Therefore, the aim of this study was to develop and validate a novel questionnaire to systematically and rapidly assess endurance athletes' key knowledge of CHO requirements for optimal performance in competition based on current sports nutrition guidelines.

3.4 Methods

3.4.1 Development of Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q)

A summary the steps in the development of the CEAC-Q can be observed in **Figure 3**. Briefly, the CEAC-Q was developed by a team of four expert sports dietitians and performance nutritionists leading research on nutrition for endurance performance and working in applied practice with amateur as well as professional endurance athletes ranging from club to world-class level. The questionnaire was formed and based on the current American College of Sports Medicine (ACSM) guidelines and recent sports nutrition research findings on CHO for endurance sports (Thomas, Erdman and Burke, 2016b; Areta and Hopkins, 2018; Impey et al., 2018). The working group identified five topic areas of key core knowledge for CHO and competition, namely: CHO storage and metabolism; CHO loading; CHO meal prior to an event; CHO during an event and CHO for recovery. The questionnaire was pilot tested on sports dietitians/nutritionists (n = 18) and endurance athletes (n = 25) providing qualitative feedback for each question and subsection to ensure adequacy of the questions and clarity of instructions during completion. The research team reviewed the pilot questionnaire results and incorporated feedback on clarity of questions, suitability, amended and endorsed content validity of the final questionnaire.

The final questionnaire (**Appendix 1**) consists of basic demographic questions and 25 multiple-choice questions divided into the five key core knowledge areas that can provide a total possible CEAC-Q score of 100. Each question was assigned +4 points for the correct response, +1 for a partial response if there were multiple answers and 0 for incorrect or unsure responses (Zinn, Schofield and Wall, 2005; Heaney et al., 2011). All questions included an 'unsure' option to reduce the possibility of guessing answers and differentiate participants with correct, incorrect or no knowledge (Zinn, Schofield and Wall, 2005). The questionnaire was administered online using SurveyMonkey software (https://www.surveymonkey.com, San Mateo, California, USA) in English with question order presented to participants in a random manner to avoid order bias (Evans et al., 2009; Regmi et al., 2016). Participants were encouraged not to guess and could provide open-ended comments for the overall questionnaire and each individual question to provide opportunity to explain answers or identify need to clarify wording (Blennerhassett et al., 2018). SurveyMonkey recorded the time to complete the questionnaire which could only be completed once, without time constraints and only completed questionnaires were included for analysis.

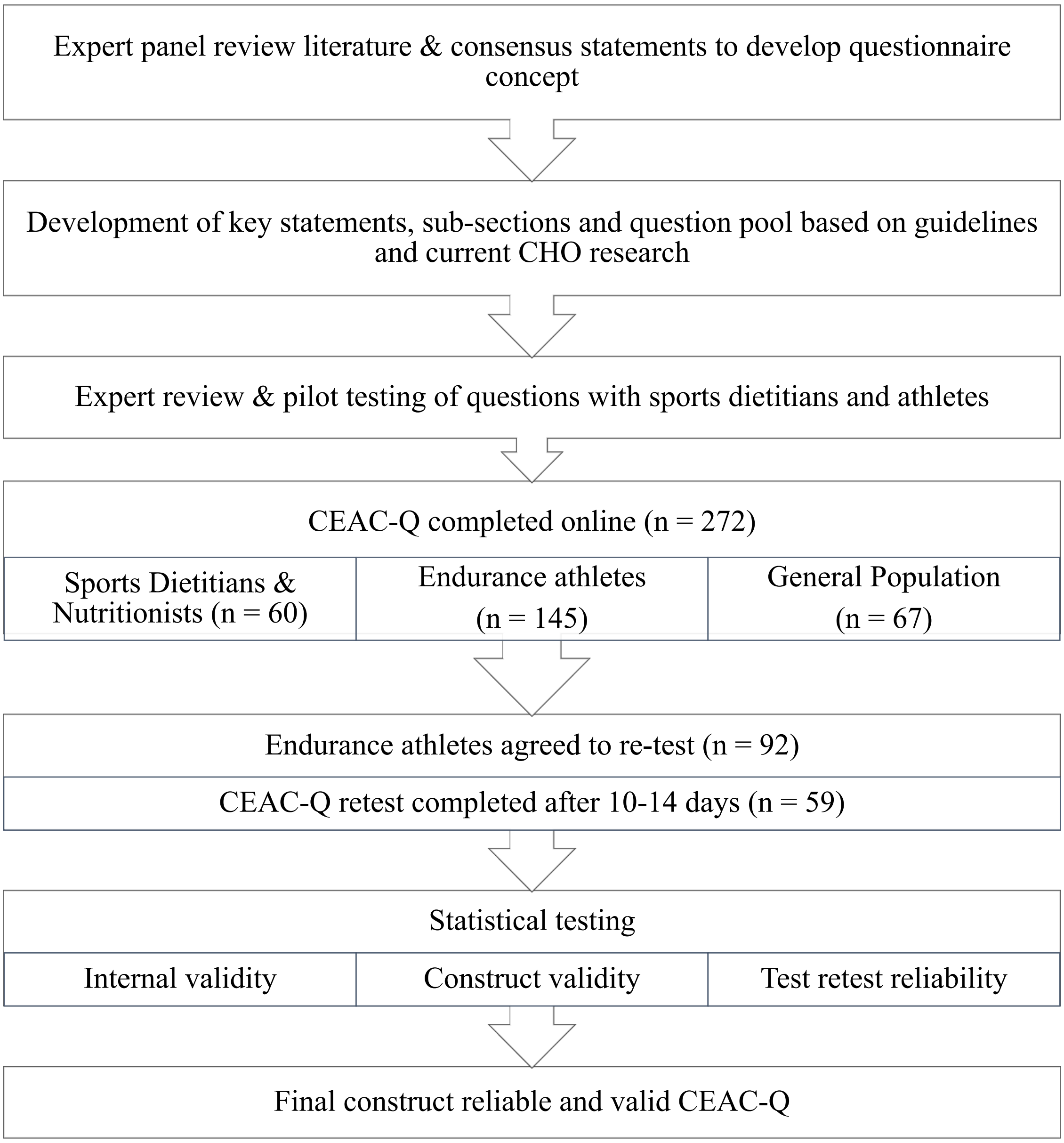


Figure 3. Schematic of process to develop the Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q)

3.4.2 Construct validity assessment

To assess construct validity, three groups with *a priori* hypothesised varying levels of sports nutrition knowledge were recruited. In order of expected level of knowledge, these were: 1) general population who did not participate in any endurance sport (GenP), 2) endurance athletes with >12 months training experience (EA), and 3) sports dietitians/nutritionists (SDN) who were registered members of Sports Dietitians Australia, the Sport and Exercise Nutrition Register, British Dietetic Association Sport Nutrition Group, International Society of Sports Nutrition or Board Certified Specialist in Sports Dietetics with the American Academy of

Sports Dietitians and Nutritionists. Participants were invited to participate through social media and email lists of sport nutrition regulatory bodies. All participants were provided with the participation statement and online consent form and agreed to participate electronically. The research was approved by the Liverpool John Moores University ethics committee (approval code 19/SPS/016) and data collection conducted between March and May 2019.

3.4.3 Test-retest reliability

To assess test-retest reliability, the athlete group were invited to complete the CEAC-Q questionnaire 10-14 days later, as a period of less than 3 weeks is considered long enough for the questions to be forgotten yet short enough to minimize any change in nutrition knowledge (Kline, 2000; Trakman et al., 2017; Trakman et al., 2018). Athletes who volunteered to complete the questionnaire a second time were contacted by email 10-14 days later with a personalised link to the test-retest CEAC-Q minus demographic questions. No nutrition education was provided or advised between tests by our team. To account for any learning between tests, athletes were asked 3 additional questions at the end of the second questionnaire: 1) whether their level of nutrition knowledge changed between tests, 2) if the CEAC-Q inspired them to learn more about sports nutrition, and 3) asked to provide open-ended details to explain how or why their knowledge changed between tests (**Appendix 1**).

3.4.4 Statistics & data analysis

One-way analysis of variance (ANOVA) was used to compare the total score and the five CHO sub-sections between groups with Post-hoc analysis Scheffe due to unequal group sizes. Statistically significant differences in knowledge total and subsection scores between the three groups was seen as evidence of construct validity of the questionnaire (Blennerhassett et al., 2018). Each of the five subsections were assessed separately for internal consistency as each addressed a different area of CHO knowledge. Internal reliability for each subsection was measured against the psychometric requirements to determine reliability with Cronbach's $\alpha > 0.7$ indicating acceptable internal consistency (Tavakol and Dennick, 2011; Furber, Roberts and Roberts, 2017). Differences in knowledge scores between groups were assessed using non-parametric (Kruskal-Wallis) analysis of variance (ANOVA) with Tukey post hoc analysis to determine which group differed when results were significant. A Bonferroni correction applied to nonparametric post hoc analysis (Trakman et al., 2018). Upon re-test, intra-class correlation coefficients or Pearson's Correlation compared nutrition knowledge scores of athletes between time points to provide evidence of test-retest reliability. With regard to potential learning effects between test and retest dependent samples t-test were conducted to evidence stability of the CEAC-Q (Kondric et al., 2013). All data are reported as means ±SDs. All data was analysed using IBM SPSS (version 24) with a significance level of $p = 0.05$. Graphs were created in Graphpad Prism 8 (GraphPad Software, Inc. v8, La Jolla, CA, USA).

3.5 Results

Participants. The CEAC-Q was completed by a total of 272 individuals of general population (GenP, n = 68), endurance athletes (EA, n = 145) and sports dietitians/nutritionists (SDN, n = 60) with demographic data of GenP and EA summarised in **Table 7**. SDN were members of the UK Sport and Exercise Nutrition Register (n = 35), Sports Dietitians Australia (n = 22) or the American Academy of Sports Dietitians and Nutritionists (n = 3). The CEAC-Q took athletes an average 10:36 ±07:45 minutes to complete.

Table 7. Demographics of General Population and Endurance athletes

		General Population n ±SD (%)	Endurance Athletes N ±SD (%)
Gender	Male	22 (32)	81 (56)
	Female	46 (68)	64 (44)
Age	Years	43.6 ±13.4	38.9 ±10.7
Education	High school certificate	18 (27)	32 (22)
	Undergraduate	31 (46)	56 (39)
	Postgraduate	15 (22)	34 (23)
	Doctorate	4 (6)	12 (8)

General population (n = 68), Endurance athletes (n = 145)

CEAC-Q scores. There was a significant difference between groups for total nutrition scores as determined by one-way ANOVA [$F(2, 269) = 172.86$, $p < 0.0001$] (**Figure 4, A**). In regards the total CEAC-Q score, GenP scored the lowest (17 ±20, mean ±SD), followed by EA (46 ±19) with the SDN group scoring the highest (76 ±10, $p < 0.001$; **Figure 4, A**). Similarly, subsection scores for all sections were significantly different between groups (3 ±5, 9 ±5 and 15 ± 4; $p < 0.001$, **Figure 4, B-F**) for GenP, EA and SDN respectively. Within EA there were no differences were between subsection scores for any of the sections ($p = 0.0674$).

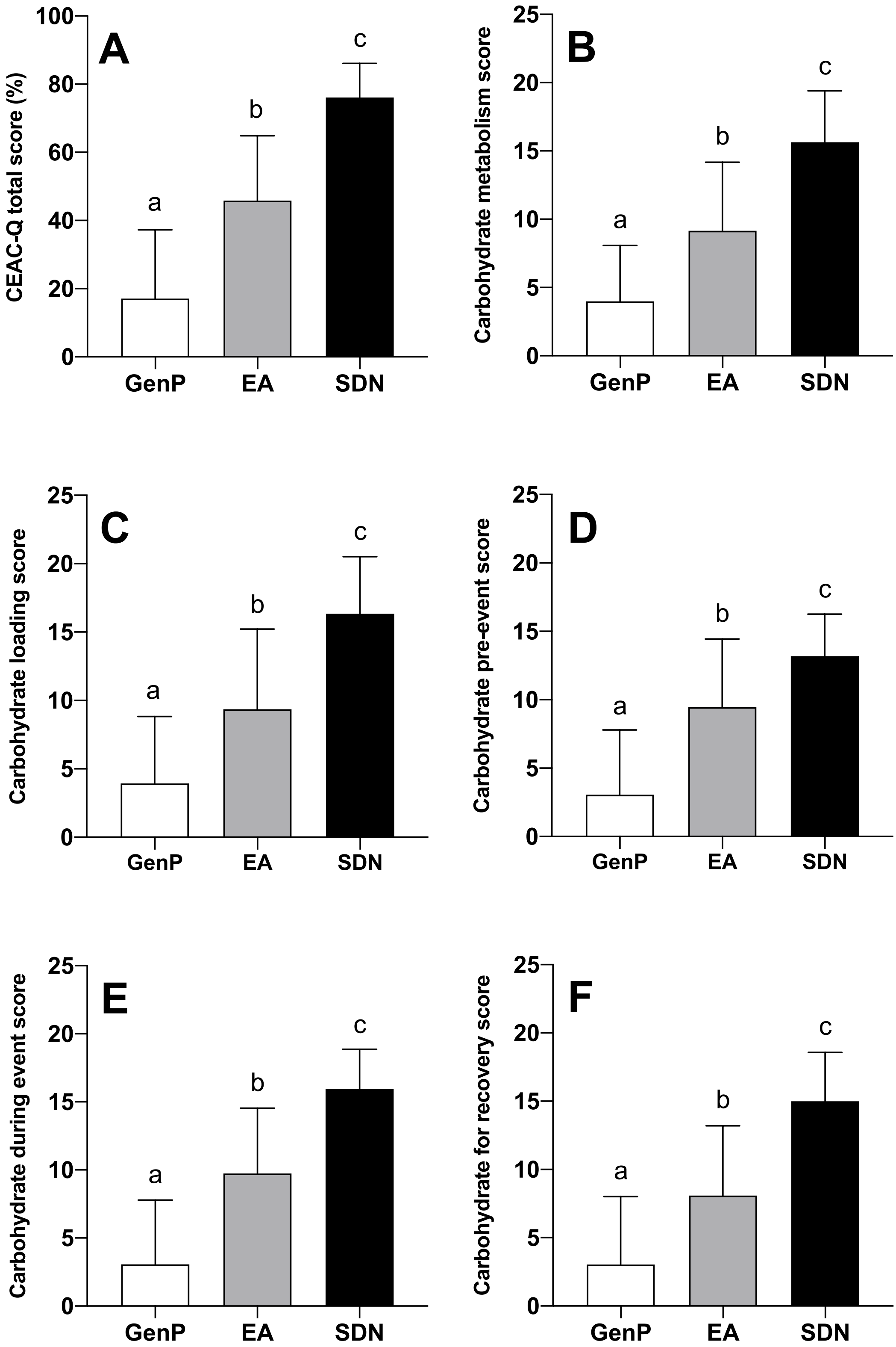


Figure 4 Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q) total and sub-section scores of general population (GenP), endurance athletes (EA) and Sport Dietitians and Nutritionists.

CEAC-Q Total score (A) Carbohydrate metabolism (B): Carbohydrate loading (C): Carbohydrate pre-event meal (D): Carbohydrate during event (E): Carbohydrate for recovery (F). Data are means ± SD. Different letters on top of each column represent statistically significant differences between groups ($p < 0.001$).

Reliability. Reliability of the final CEAC-Q as measured by Cronbachs alpha in the athlete group was 0.82. Reliability scores for the individual CEAC-Q subsections were as follows: CHO metabolism (0.72), CHO loading (0.74), Pre-event CHO meal (0.79), During event CHO (0.85), Post-event recovery CHO (0.79). All scores were > 0.7 demonstrating acceptable evidence for internal consistency and reliability of each subsection of the questionnaire (Tavakol and Dennick, 2011; Furber, Roberts and Roberts, 2017). Removal of any questions and subsections reduced the internal consistency of the CEAC-Q.

Test-retest reliability. Of the total 145 athletes initially recruited, 59 EA completed a second test. The retest showed a significant learning effects between test (44 ±20) and retest (53 ±18, p < 0.001). Scores increased by 8 ±14 points (**Table 8,** p < 0.001) with a wide inter-participant variation range in the change. The majority of athletes (76.3%, n = 45) increased CEAC-Q scores on re-test by an average +13 ±12 points, while 14 participants' scores decreased between tests by -6 ±4 points. The majority of athletes (91.5%, n = 54) indicated that completing the CEAC-Q motivated them to learn more about sports nutrition, with 72.9% (n = 43) believing their knowledge level had increased between tests. Open-ended responses were provided by 26 participants explaining how and why knowledge changed between tests. Responses were grouped into four primary themes; raised awareness of current knowledge gaps, self-directed learning, selecting unsure to avoid guessing incorrectly and applying knowledge into practice, with some comments applicable to multiple themes (**Table 9**).

Table 8. Endurance athlete CEAC-Q scores test-retest reliability

Knowledge Section (n = 59)	Test 1	Test 2	Difference	Pearson's Correlation coefficient	Significance of difference (p)
Section 1 CHO metabolism	9 ±5	11 ±5	2 ±5	0.459	0.008
Section 2 CHO loading	9 ±6	11 ±5	2 ±5	0.609	< 0.001
Section 3 CHO pre-event	9 ±5	10 ±4	1 ±4	0.542	0.079
Section 4 CHO during	10 ±4	12 ±5	1 ±4	0.645	0.016
Section 5 CHO recovery	8 ±5	10 ±5	2 ±5	0.610	0.002
Total CEAC-Q score	44 ±20	53 ±18	8 ±14	0.742	< 0.001

Reliability of total and subsection CEAC-Q scores (mean ±SD) between initial test and retest 10-14 days later.

Table 9. Qualitative open-ended responses for athletes who reported a change in knowledge following completion of CEAC-Q (n = 26).

Theme	n	Representative quote
Raised awareness of current knowledge gaps regarding CHO and competition specific nutrition	11	*Thank you, your survey has highlighted how little I know about fuelling nutrition for triathlon training. I can now do some research to help my performance.*
Engaged in self-directed learning after the first test to increase knowledge of CHO for performance	12	*I've read a few articles since originally completing it. I did look at some articles around carbohydrates post questionnaire as it spiked an interest.*
Selected unsure (+0 points) in one test to avoid guessing incorrectly but not the other (+4 points)	8	*I think I'm in a different mood to when I first did the survey, I think I clicked 'unsure' more the first time whereas this time I didn't at all, but I don't think my knowledge has changed.*
How is knowledge applied in practice?	4	*"It's made me think I SHOULD learn more. But whether or not I act on it is questionable.*

3.6 Discussion

The main findings of this study were that 1) the Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q) is a fast (~10 min) and valid tool to assess CHO knowledge for competition in endurance athletes, and 2) the CEAC-Q can identify knowledge gaps and raise awareness of that gap within athletes.

To our knowledge, the CEAC-Q is the first CHO-specific nutrition knowledge questionnaire designed for use with endurance athletes to understand gaps in knowledge of current CHO recommendations. Previous general nutrition knowledge questionnaire studies have observed both poor CHO specific knowledge in athletes (Spendlove et al., 2011) as well as inadequate CHO intakes during competition in elite and amateur athletes (Cox, Snow and Burke, 2010; Masson and Lamarche, 2016; McLeman, Ratcliffe and Clifford, 2019). Inadequate nutrition knowledge is one of multiple barriers influencing athletes capacity to eat appropriately (Heaney et al., 2008). A key role of a sports dietitian is to provide targeted nutrition coaching based upon topics that are poorly understood by their athletes (Trakman et al., 2018). By using the CEAC-Q to specifically evaluate knowledge of CHO for optimal performance before, during and after competition, it is possible for sports dietitians to rapidly identify these knowledge gaps to provide bespoke education during the nutrition coaching process (Bentley et al., 2019; Bentley, Mitchell and Backhouse, 2020).

Although the CEAC-Q focuses specifically on CHO, total knowledge scores were comparable to those of other general sports nutrition knowledge questionnaires conducted in athletes. Five of seven studies included in a meta-analysis of general nutrition knowledge questionnaires reported athlete mean knowledge scores greater than 50%, ranging from 43 to 68% (Heaney et al., 2011). The longer original 89-item nutrition for sport knowledge questionnaire (Trakman et al., 2017) and shortened 37-item abridged nutrition for sport knowledge questionnaire (Trakman et al., 2018) reported nutrition knowledge scores in athletes of 49% and 46% respectively. Trakman et al. (2018) determined construct validity between individuals with formal nutrition education (65%) and individuals with no formal nutrition education (52%), and Karpinski, Dolins and Bachman (2019) found 55% of athletes correctly answered general sports nutrition knowledge questionnaires. With a distinct CHO section worth 11 points, athletes scored 4 ±3 (32%) against sports dietitians 8 ±2 (71%), although incorrect answers were scored negatively (Karpinski, Dolins and Bachman, 2019). Similar to these, the CEAC-Q total scores (**Figure 4A**) show that EA had superior nutrition knowledge (46%) than the GenP (17%), but less than SDN (76%). The clear distinction demonstrates construct validity of the CEAC-Q and suggests that rather than being common knowledge, CHO specific sports nutrition knowledge may be learnt by participation within endurance sport, with knowledge increasing incrementally between general population, athletes and sports dietitians.

An unexpected finding was a small but significant learning effect of the CEAC-Q to allow athletes to self-identify gaps in their own knowledge and inspire self-directed learning to fill these knowledge gaps. Indeed, retest of the CEAC-Q 10-14 days after, in a subgroup of 59 EA resulted in an increased score of 8 ±14 % ($p = < 0.001$) for 54 athletes (92%). This increase occurred despite participants receiving no feedback regarding scores or formal education being provided between tests. Qualitative comments suggest this difference in scores may partially be explained if participants selected unsure to avoid guessing incorrectly in one test but not for the other; *"I think I clicked 'unsure' more the first time whereas this time I didn't at all... but I* *don't think my knowledge has changed.”.* The majority of athletes believed that their knowledge increased (n = 43, 73%) and reported being motivated to learn more about sports nutrition for competition (n = 54, 92%) after completing the CEAC-Q. Athletes naturally seek to gain any competitive advantage; becoming aware of gaps in their knowledge may seek to improve between two tests (Kondric et al., 2013). By completing the CEAC-Q, some athletes were made aware of gaps in their own knowledge which motivated them to engage in self-directed learning “A*fter answering "Unsure" on most of the questions the first time round I looked up some of the info online to get a better understanding”.* The act of completing the CEAC-Q may set in chain thinking processes leading to new insights or knowledge (Taber, 2017). As scores are expected to increase following self-education, a different and small random error in repeat tests indicates good reliability and construct validity as it suggests learning processes at work (George, Batterham and Sullivan, 2000; Batterham and George, 2003).

A key role of sports dietitians is to support positive change in the dietary behaviour of athletes utilizing a range of nutrition-coaching interventions (Bentley et al., 2019; Bentley, Mitchell and Backhouse, 2020). In the theoretical framework of the *COM-B* model of behavior change, improving the physical and psychological *capability, opportunity* and *motivation* of individuals are essential to drive behavior change (Michie, van Stralen and West, 2011; Michie et al., 2013). An unanticipated result was the ability of the CEAC-Q to internally motivate an athlete to engage in self-directed learning to correct knowledge gaps, despite no feedback being provided upon completion. However, as one participant reported, increased knowledge or awareness doesn’t necessarily translate to a change in behaviour: “*It’s made me think I SHOULD learn more. But whether or not I act on it is questionable.”* A good nutrition coaching program should enhance enablers and reduce barriers to support behaviour change (Bentley et al., 2019) and provide targeted advice based upon nutrition topics that are poorly understood by athletes (Trakman et al., 2018). Our findings support the idea that using the CEAC-Q as a screening tool can help increase theoretical and practical knowledge (capability) by identifying gaps in knowledge of current CHO guidelines that may require targeted education. Thus, the CEAC-Q can be a useful tool for sports dietitians aiming to influence and empower their athletes to change nutritional intake during competition for optimal performance.

The main limitations of the current questionnaire are the time frame between tests, control over participant test conditions, self-learning and bias in nutritional beliefs. Previous nutrition knowledge validation studies considered a period of 3 weeks long enough for answers to be forgotten yet short enough to minimize any change in nutrition knowledge (Furber, Roberts and Roberts, 2017; Trakman et al., 2017; Blennerhassett et al., 2018; Trakman et al., 2018). Test conditions should be consistent in repeat trials, however for a self-administered test, no control could be placed over distractions or how much attention a participant takes when completing (Batterham and George, 2003). No nutrition education or feedback on scores were provided between tests, however athletes participating in the retest may have been personally invested in the topic and more motivated to increase their knowledge, which could not be controlled by investigators (Trakman et al., 2018).

The current findings open up avenues for future research to assess and enhance dietary practices of endurance athletes within competitive settings. Completing the CEAC-Q with a larger cohort of endurance athletes will allow differentiation between known confounders of nutrition knowledge in a competitive setting: age, sex, level of education as well as potential confounders including living situation, level physical activity ethnicity, athletic calibre and type of sport (Spendlove et al., 2011). However, as increased knowledge or awareness may not necessarily directly translate in improved nutritional practices (Alaunyte, Perry and Aubrey, 2015) future studies should use the CEAC-Q in a competitive setting to assess the relationship between CHO knowledge and practice. This will allow sports dietitians to further understand why athletes fail to achieve recommended CHO intakes and subsequently develop more effective, improved athlete nutrition-education resources and programs to optimise endurance performance.

3.7 Reflective pause (Study 1)

An unexpected finding during the test-retest reliability data analysis was that the CEAC-Q acted as a learning tool and could potentially motivate athletes to change their behaviour or want to learn more. However, this also raised lingering doubts in the quality of my research and usefulness of the CEAC-Q in practice. "*The 2-week test-retest protocol was based on previous [nutrition knowledge] studies. But that was probably not right as we hadn't accounted for the fact that athletes would be hungry to learn more, and their scores would increase. It matters. I hadn't considered the learning effect until after we had been collecting the re-test data and seeing the comments and changes. Does this make it bad research? (24.6.20).* Learning to let go of perfectionism and not be negatively impacted by external circumstances but to stick to my goals, remain focused on what I was trying to achieve is an ongoing process as I work towards my vision for my life, my research my future. "*The mark of a champion is the ability to win when things are not quit right – when you're not playing well, and your emotions are not the right ones*" – Carol Dweck (1.5.18).

It was only once I took ownership and used it myself in practice that I truly gained confidence and believed the CEAC-Q was valuable. "*I only learn confidence by doing. Not by observing. Doing! It's the doing and the action where the confidence is built! (4.3.18)*. When presented my initial findings at the ISENC conference in 2019 and again at a virtual online nutrition conference, I received positive feedback from other dietitians regarding the usefulness of the questionnaire which provided further reassurance in the wider impact of my work. I began to see how my research could provide a *"clear understanding of what the gaps in knowledge are regarding CHO intake during competition periods, whether to place appropriate interventions, and the barriers that influence the mismatch between recommendations, knowledge and implementation practice (18.3.19)"*. But just being aware of a gap in knowledge doesn't necessarily translate to a change in action: "*It's made me think I SHOULD learn more. But whether or not I act on it is questionable."* which raised questions regarding what does motivate an athlete to act and how can that be used to change their behaviour?

Chapter 4

Assessment of knowledge of carbohydrate guidelines for competition in an international cohort of endurance athletes using the CEAC-Q.

(Study 2)

4.1 Research orientation Study 2

At this phase of the Professional Doctorate, I was working part-time as a sports nutritionist for Team Dimension Data professional cycling team, with a few hours of private practice. During the validation study in **Chapter 3**, I noticed a trend that did not reach significance whereby athlete nutrition scores increased as they became more experienced and more elite within their sport. Likewise, athletes who had previously or currently worked with a sports dietitian/nutritionist seemed to report better scores than those who hadn't. Despite wide inter-participant variation in scores, no clear differences were observed between total or sub-section CEAC-Q scores obtained amongst athletes. The question was raised whether a larger cohort of endurance athletes would identify any clear or significant differences in nutrition knowledge between different sports, genders, levels of experience and years of sport participation. As a profession, how well have sports dietitians shared or explained nutrition guidelines to athletes over the last decade? What do they and don't they know about CHO for performance at a population level? By recruiting a large cohort of international endurance athletes competing at multiple levels for Study 2, the aim was to acquire a good understanding of current knowledge levels during competition. This data could be used to identify any trends and patterns and whether there were certain subsections of CHO knowledge that were more misunderstood by athletes than others. As a sports dietitian, the relevance of this information would allow identification of areas where there is a greater need for sports nutrition education and support amongst athletes and also provide a comparison for current population level norms.

4.2 Abstract

Purpose: Adequate nutrition knowledge is an essential component to drive athlete's behaviour and optimise general dietary intake, yet little is known about endurance athletes' (EA) understanding of carbohydrate (CHO) guidelines and how this relates to practice within competition. Having developed a suitable CHO knowledge assessment tool, this study assessed current knowledge of CHO guidelines in an international cohort of endurance athletes using the Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q).

Methods: The CEAC-Q was completed online by EA (n = 1016) actively competing in endurance sporting events, including cycling, triathlon and running. Associations between CEAC-Q scores and demographic variables were examined using univariate ANOVA and stepwise multiple regression.

Results: Mean CEAC-Q total and subsection scores were 50 ±20% and 10 ±5, respectively. Multiple regression determined that years of competitive experience, competitive level and a sports nutritionist influence were positively related to CEAC-Q scores. Clear knowledge gaps transpired where correct knowledge of current CHO guidelines was shown by 28% (n = 284) for CHO loading, 45% (n = 457) for the pre-competition meal, 48% (n = 487) for during competition lasting >2.5 h and 29% (n = 296) for post-competition recovery.

Conclusion: The CEAC-Q identified areas of high, medium and low knowledge of endurance athletes in different key knowledge areas of CHO for competition in an international cohort. Common gaps in knowledge of CHO guidelines that require further education were identified that may partially explain why athletes consume suboptimal CHO within competition.

4.3 Introduction

Carbohydrates (CHO) are well-known to enhance performance of endurance athletes, with international guidelines advising optimal CHO intakes before, during and after competition (Jeukendrup, 2004; Burke et al., 2011; Thomas, Erdman and Burke, 2016a; Kerksick et al., 2017). Despite these guidelines, a clear mismatch exists between CHO guidelines and dietary intakes within competition (Heikura et al., 2017b; Sparks et al., 2018; McLeman, Ratcliffe and Clifford, 2019). As an illustrative example of the mismatch, pre-competition CHO intake is recommended to be 9 - 12 $g\bullet kg^{-1}.day^{-1}$ for 28 - 48 h prior to a prolonged event, however suboptimal CHO intakes of 2.5 - 7.3 $g\bullet kg^{-1}$ have been systematically reported on the day prior to competition (Havemann and Goedecke, 2008; Atkinson et al., 2011; Armstrong et al., 2012; Masson and Lamarche, 2016; Pugh et al., 2018; McLeman, Ratcliffe and Clifford, 2019; Wardenaar et al., 2019). Furthermore just 50% of triathletes, 30% of cyclists and 15% of marathon runners consumed the recommended 60 - 90 $g\bullet h^{-1}$ during events lasting >2.5 h (Havemann and Goedecke, 2008; Armstrong et al., 2012; Black, Skidmore and Brown, 2012; Pfeiffer et al., 2012; Pugh et al., 2018; McLeman, Ratcliffe and Clifford, 2019). The remarkable mismatch between current guidelines and intakes of endurance athletes during competition makes it pertinent to enquire about the level of knowledge of the guidelines on the athlete population.

Adequate nutrition knowledge is an essential component to drive athlete's behaviour and optimise general dietary intake (Spronk et al., 2015), yet little is known about endurance athletes' understanding of these CHO guidelines and how this relates to practice. Whether this mismatch is due to endurance athletes' inadequate knowledge of CHO guidelines or other reasons is currently unknown. Having developed a validated tool to address this, we will assess current knowledge levels of an international population of endurance athletes using the Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q; **Chapter 3**).

4.4 Methods

4.4.1 Study design

This study assessed current CHO nutrition knowledge levels of an international cohort of endurance athletes using the Carbohydrates for Endurance Athletes in Competition

Questionnaire (CEAC-Q, **Appendix 1**) in English language between August 2019 and June 2020. Endurance athletes aged >18 years self-opted to participate if they were actively training and competing in endurance sporting events, including cycling, triathlon and running. The CEAC-Q was shared online through social media using SurveyMonkey software (https://www.surveymonkey.com, San Mateo, California, USA) and scored as previously described in Chapter 3. All participants were provided with the participant information statement and online consent form and electronically agreed to participate. The research was approved by the Liverpool John Moores University ethics committee (approval number 19/SPS/025).

4.4.2 Data analysis

Data means and standard deviations were determined for CEAC-Q total and subsection scores. Associations between CEAC-Q scores and independent variables were examined using univariate ANOVA and stepwise multiple regression was run to determine which demographic variables predicted CEAC-Q score. Statistical significance was set at $P < 0.05$. Data analyses were conducted in IBM SPSS Version 26 (IBM Corp, Armonk, New York).

4.5 Results

4.5.1 Participant characteristics

The CEAC-Q was completed online in English by 1016 athletes (55% male, 46% female); mean age 36.7 ±10.7 years from the United Kingdom (n = 405, 40%), Australia/New Zealand (n = 221, 22%), the United States of America/Canada (n = 180, 18%) and other countries (n = 210, 21%). Mean self-reported body mass of male and female athletes was 75.1 ±11.5 kg and 60.7 ±8.8 kg respectively. Athletes competed primarily in cycling (n = 400, 39%), triathlon (n = 342, 34%) and running events (n = 254, 25%). Other endurance athletes (n = 20, 2%) participated in rowing, race walking, cross country skiing, spartan or obstacle races and open water swimming. Demographic data collected on competitive experience in the sport, education, whether athletes had worked with a nutritionist or dietitian and their primary source of sports nutrition information is summarised in **Table 10** with subsequent CEAC-Q scores.

Table 10. Participant demographics and corresponding CEAC-Q score per sub-group.

Characteristic		Frequency n (%)	CEAC-Q score % ±SD
	All	1016 (100)	50 ±20
Gender	Male	562 (55)	51 ±20
	Female	454 (45)	48 ±20
Age (years)	18-29	283 (28)	54 ±19
	30-39	370 (36)	53 ±20
	40-49	218 (22)	46 ±20
	>50	145 (14)	41 ±19
Education	High school certificate	279 (27)	46 ±20
	Undergraduate	407 (40)	50 ±19
	Postgraduate	273 (27)	53 ±21
	Doctorate	56 (6)	56 ±21
Sport	Cycling	400 (39)	52 ±21
	Triathlon	342 (34)	48 ±19
	Running	254 (25)	50 ±20
	Other	20 (2)	45 ±23
Competition level	Amateur recreational	288 (28)	45 ±20
	Amateur regional	263 (26)	47 ±21
	Amateur national	203 (20)	55 ±21
	Amateur international	156 (16)	53 ±18
	Professional	106 (10)	57 ±16
Years competing	<1 year	51 (5)	38 ±20
	1-3 years	235 (23)	47 ±21
	3-5 years	226 (22)	51 ±19
	5-10 years	238 (23)	52 ±20
	>10 years	266 (26)	53 ±19
Worked with Nutritionist	No nutritionist	732 (72)	47 ±20
	Yes nutritionist	284 (28)	58 ±17
Primary source of nutrition information	Self-directed learning	526 (52)	49 ±19
	Nutritionist	146 (14)	57 ±17
	Don’t seek nutrition information	81 (8)	40 ±24
	Coach	76 (8)	47 ±15
	Other athletes	81 (8)	39 ±18
	Scientific journals	47 (5)	71 ±16
	Sports scientist	38 (4)	59 ±19
	Friends and family	16 (2)	32 ±20
	Other	5 (1)	56 ±18

For each parameter there were significant differences in CEAC-Q scores between the subgroup divisions ($P < 0.001$) except Gender ($P = 0.033$) and Sport ($P = 0.047$)

4.5.2 Carbohydrate nutrition knowledge scores of endurance athletes (CEAC-Q)

Mean CEAC-Q total scores were 50 ±20%, showing a typical normal distribution (**Figure 5A**) and were different between cyclists (52 ±21%), triathletes (48 ±19%,) runners (50 ±20%) and other endurance athletes (45 ±23%; p = 0.047). Male athletes scored higher than females (51 ±20% vs 48 ±20%, p = 0.033). CEAC-Q scores increased with competitive experience with recreational athletes scoring significantly lower than professional athletes (**Table 10**, 45 ± 20% vs 57 ±18%, p < 0.001) respectively. Over half the athletes surveyed (n = 526, 52%) used self-directed learning including websites, books and podcasts as their primary source of sports nutrition information; achieving considerably lower CEAC-Q scores than those who referred to scientific journals for their advice (**Table 10,** 49 ±19% vs 71 ±16%, p < 0.001). Most athletes (n = 732, 72%) had never seen a sports dietitian or nutritionist, achieving lower CEAC-Q scores than athletes who had (47 ±20% vs 58 ±17%, p = < 0.001). Stepwise multiple regression identified that years competing, competition level, gender, education level, worked with nutritionist, primary source of nutrition information, weight and age statistically significantly predicted CEAC-Q score, but the predictive power was poor F(8,1003) = 37.42, p <0.001, R^2 = 0.23.

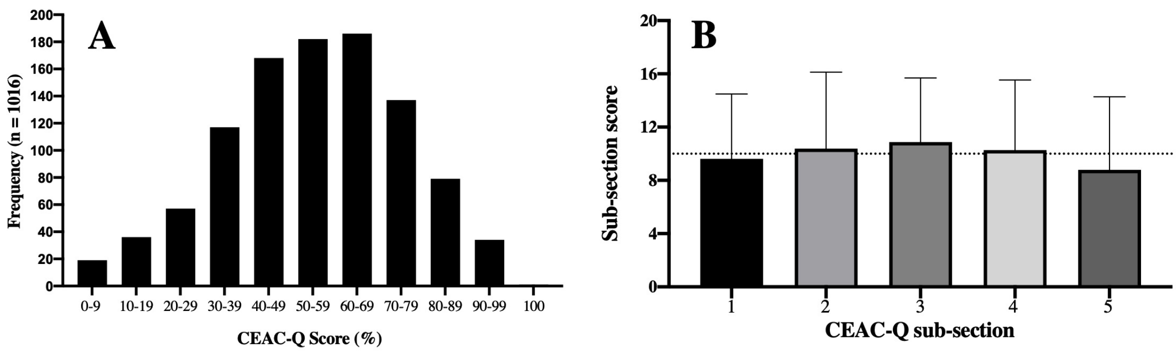


Figure 5. Mean total CEAC-Q score frequency distribution chart and CEAC-Q subsection score

A) Total CEAC-Q score mean ±SD (50 ±20%) is calculated from the sum of the following 5 subsections worth 20 points each for a maximum 100 points; B) Section 1 CHO metabolism (10 ±5); Section 2 CHO Loading (10 ±6); Section 3 CHO pre-event (11 ±5); Section 4 CHO during (10 ±5); Section 5 CHO recovery (9 ±6). Only 1 participant scored 100%. Dotted lines represent mean values.

4.5.3 CEAC-Q subsections and questions identify specific carbohydrate knowledge gaps

No differences were observed between mean CEAC-Q subsection scores (**Figure 5B,** 10 ±5,). To provide a detailed insight into the knowledge of each question at a population level we have detailed ranked analysis of the proportions of questions within each of the 5 sub-sections answered correctly (**Figure 6**) followed by the frequency of responses chosen in **Table 11**. Clear knowledge gaps of current CHO guidelines were evident as only a third of endurance athletes correctly identified 9 - 12 g•kg•h^{-1} for CHO loading (**Table 11 Q8**; 28%) or 1.2 g•kg•h^{-1} CHO post-exercise for recovery (**Table 11 Q22**; 29%). Similarly, only half of athletes correctly identified to consume 1 - 4 g•kg^{-1} CHO in the pre-event meal (**Table 11 Q11**; 45%), 30 - 60 g•h^{-1} or 60 - 90 g•h^{-1} during competition lasting 1 – 2.5 h or >2.5 h in duration (**Table 11 Q18b,c;** 53%, 48% respectively).

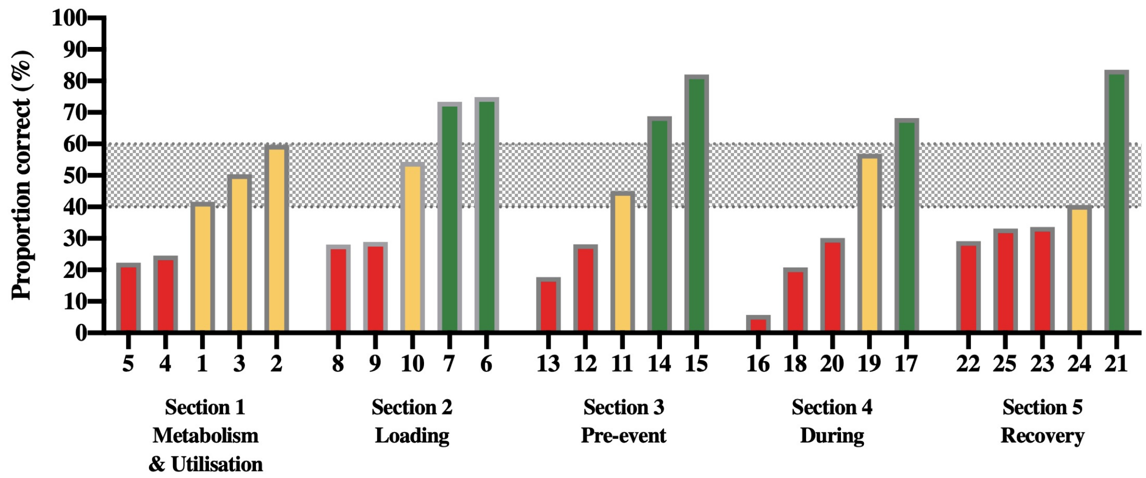


Figure 6. Ranked proportion of correctly answered CEAC-Q questions per subsection.
Questions ranked in order from lowest to highest proportion of correct answers per subsection; A) Section 1 CHO metabolism; B) Section 2 CHO Loading; C) CHO pre-event; D) Section 4 CHO during; E) Section 5 CHO recovery. A traffic light system represents questions with low (<40%), medium (40-60%) and high (>60%) knowledge.

Knowledge gaps of CHO metabolism, optimal practices and ways in which can improve performance were also evident, as just 17% were aware that consuming CHO during exercise could reduce the energy cost of exercise, or that it could stimulate the nervous system (**Figure 6D, Table 11 Q16,** 20%). Similarly, only 22% of athletes knew that the liver is the primary source of CHO used to maintain normal blood sugar levels (**Table 11 Q5; Figure 2A**) or that the primary reason to consume CHO in the hours before exercise is to replenish liver glycogen stores (**Table 11 Q13; Figure 2C,** 18%). While 54% of athletes correctly identified that CHO loading can be achieved with 24 - 48 h of optimal CHO intake, 21% of athletes reported a week is necessary and 11% believe that CHO loading is never required for optimal performance (**Table 11; Q10**). Likewise, half of athletes (50%) understood that the body can absorb approximately 60 g•h^{-1} of CHO during exercise from a single source, only 40% knew that this could be increased to 90 g•h^{-1} when multiple sources of CHO are consumed (**Table 11 Q20**), and just a third understood that with optimal CHO intake glycogen levels could be restored within 12 - 24 hours (**Table 11 Q23**; 34%).

Table 11. CEAC-Q responses for each individual question identify knowledge gaps

	CEAC-Q Question	CEAC-Q answer choices	Frequency of answers % (N)
Subsection 1: CHO Metabolism and Utilisation	1. Which factor(s) influence how much carbohydrate our body uses during exercise? *(Select all that apply)*	**Exercise intensity**	**84 (858)**
		Exercise duration	**83 (841)**
		Environment	**55 (555)**
		Training status	**53 (541)**
		Carbohydrate never required	2 (16)
		Unsure	6 (60)
	2. Which of the following carbohydrate related factors contribute to fatigue during exercise?	Low blood sugar	2 (20)
		Low muscle glycogen	28 (279)
		Low blood sugar AND glycogen	**60 (607)**
		Carbohydrate not required	1 (12)
		Unsure	10 (98)
	3. In a carbohydrate loaded state, carbohydrate is stored in the body as:	Muscle only	5 (46)
		Liver only	1 (9)
		Muscle 80% liver 20%	**50 (512)**
		Muscle 20% liver 80%	20 (200)
		Carbohydrate not stored	0.4 (4)
		Unsure	24 (245)
	4. In a carbohydrate loaded state, total carbohydrate storage in the body is approximately:	< 200 g	10 (103)
		200 – 400 g	23 (235)
		400 – 600 g	**25 (249)**
		Carbohydrate not stored	1 (7)
		Unsure	42 (422)
	5. Which source of carbohydrate stores is used to maintain normal blood sugar during exercise?	Muscle only	15 (148)
		Liver only	**22 (227)**
		Muscle and liver	33 (337)
		Carbohydrate not stored	1 (14)
		Unsure	29 (290)
Subse...	6. Carbohydrate loading in the days before a competitive endurance event can increase endurance performance by?	Cannot increase	8 (82)
		Increase max speed	9 (95)
		Delay onset fatigue	**75 (761)**

		Unsure	8 (78)
	7. Carbohydrate loading to maximise glycogen stores is most effective in improving performance in competitive events lasting:	<60 min	3 (31)
		60 - 90 min	8 (85)
		>90 min	**73 (746)**
		Carbohydrate unnecessary	6 (57)
		Unsure	10 (97)
	8. When carbohydrate loading before competition, the recommended range of carbohydrate intake per day is? *(assuming exercise activity the day before is minimal)*	< 4 g•kg•day	4 (44)
		4 - 8 g•kg•day	22 (227)
		9 - 12 g•kg•day	**28 (284)**
		> 12 g•kg•day	2 (16)
		Carbohydrate never required	4 (44)
		Unsure	40 (401)
	9. When competing WITHOUT carbohydrate loading, the recommended range of carbohydrate intake per day is? *(assuming exercise activity the day before is minimal)*	< 4 g•kg•day	21 (216)
		5 - 8 g•kg•day	**28 (294)**
		9 - 12 g•kg•day	5 (53)
		> 12 g•kg•day	1 (7)
		Carbohydrate never required	2 (16)
		Unsure	42 (430)
	10. To maximise muscle glycogen stores, carbohydrate loading (in combination with a tapering of training loads) is best followed for:	12 – 24 h	11 (112)
		24 – 48 h	**54 (552)**
		A week	21 (210)
		Never	3 (31)
		Carbohydrate loading never required	11 (111)
Subsection 3: CHO Pre-event meal	11. How much carbohydrate should a meal eaten before competition contain (in grams per kilogram body mass)?	<1g	4 (45)
		1 - 4g	**45 (457)**
		>4g	13 (129)
		Carbohydrate never required	1 (13)
		Unsure	37 (372)
	12. When is eating a meal or snack rich in carbohydrate likely to improve performance?	<60 min	7 (74)
		>60 min	53 (543)
		Never	2 (16)
		Always	**28 (286)**
		Unsure	10 (97)
	13. Eating a meal rich in carbohydrate in the hours before competition specifically helps to:	Muscle glycogen	29 (294)
		Liver glycogen	**18 (180)**
		Both	25 (255)
		Carbohydrate never required	6 (59)
		Unsure	22 (228)
	14. A meal rich in carbohydrate should be eaten how many hours before competition	<1 h	0.8 (8)
		1 - 4 h	**69 (699)**
		>4 h	22 (225)
		Carbohydrate never required	1 (14)
		Unsure	7 (70)
	15. Which of the following statements is correct regarding carbohydrate intake and gastrointestinal distress:	Never	0.9 (9)
		Gut not trained	3 (27)
		Gut can be trained	**82 (833)**
		Unsure	15 (147)

Subsection 4: CHO during event	16. Consuming carbohydrate during exercise can improve endurance performance by: *(Select all that apply)*	**Maintain blood sugar**	**59 (596)**
		Glucose	**71 (722)**
		Reduce energy cost	**17 (168)**
		Stimulate nervous system	**20 (204)**
		Carbohydrate never required	2 (15)
		Unsure	11 (110)
	17. Holding a small amount of a carbohydrate drink in the mouth for 10-15 seconds (e.g. mouth rinsing the drink) during competition:	**Act as stimulant**	**68 (693)**
		Only if swallowed	7 (59)
		No effect	6 (57)
		Negative effect	0.1 (1)
		Carbohydrate never required	0.3 (3)
		Unsure	20 (203)
	18a. How much carbohydrate is recommended per hour during competition lasting <1 hour?	None	33 (337)
		Mouth rinse or <30 g	**35 (356)**
		30 - 60 g	10 (97)
		60 - 90 g	2.0 (20)
		>90 g	0.2 (2)
		Unsure	19 (191)
	18b. How much carbohydrate is recommended per hour during competition lasting 1 – 2.5 hours?	None	1 (11)
		Mouth rinse	9 (94)
		30 - 60 g	**53 (536)**
		60 - 90 g	15 (154)
		>90 g	1 (10)
		Unsure	20 (199)
	18c. How much carbohydrate is recommended per hour during competition lasting > 2.5 hours?	None	0.5 (5)
		Mouth rinse	0.5 (5)
		30 - 60 g	26 (263)
		60 - 90 g	**48 (487)**
		>90 g	6 (58)
		Unsure	19 (194)
	19. If you take either a sports drink or energy gel containing 25g carbohydrate during exercise, would there be any difference in the amount of carbohydrate that is used by the body? *(when equal amounts of fluid is taken)*	Yes drink more	9 (86)
		Yes gel more	9 (79)
		No differences	**60 (578)**
		Carbohydrate never required	1 (7)
		Unsure	25 (256)
	20a. How much carbohydrate consumed per hour during competition is your body able to absorb and use for single source of carbohydrate?	None	0.5 (5)
		30 - 60 g	**50 (510)**
		60 - 90 g	18 (179)
		>90 g	2 (15)
		Unsure	29 (299)
	20b. How much carbohydrate consumed per hour during competition is your body able to absorb and use for multiple sources of carbohydrate?	None	0.4) (4)
		30 - 60 g	19 (188)
		60 - 90 g	**40 (405)**
		>90g	8 (79)
		Unsure	33 (339)
Sectio	21. After glycogen depleting exercise, muscle glycogen stores recover the fastest when carbohydrate is eaten?	**Early**	**84 (848)**
		Late	2 (16)
		No change	2 (22)

		Carbohydrate never required	2 (20)
		Unsure	11 (110)
	22. In the first four hours after glycogen depleting exercise, how much carbohydrate should you eat to maximise recovery of muscle glycogen stores?	<0.5	2 (17)
		0.5 - 1	13 (136)
		1 - 1.2	**29 (296)**
		>1.2	10 (99)
		Carbohydrate doesn't help recovery	2 (20)
		Unsure	44 (448)
	23. With optimal carbohydrate intake, how long would it take to fully restore muscle glycogen stores to pre-exercise levels after glycogen depleting exercise?	0 - 12 h	13 (132)
		12 - 24 h	**34 (341)**
		24 - 72 h	23 (229)
		Carbohydrate never required	1 (11)
		Unsure	30 (303)
	24. To maximise recovery of muscle glycogen stores within 8 hours post-exercise:	**Moderate to high GI**	**41 (413)**
		Low GI	17 (171)
		No difference	5 (49)
		Carbohydrate never required	1 (13)
		Unsure	36 (370)
	25. Can eating protein, in addition to carbohydrate, help to maximise muscle glycogen recovery after exercise?	**Sub-optimal CHO small amount protein**	**33 (336)**
		Small CHO high Protein	10 (103)
		No difference	12 (12)
		Carbohydrate never required	1 (13)
		Unsure	43 (438)

CEAC-Q was completed by 1016 athletes. All questions had one 'correct' response, except for Q1 and Q16 which had 4 answers each worth 1 point. Questions 18 and 20 had three and two parts, respectively. Correct answers shaded and highlighted in BOLD with a traffic light system representing questions with low (<40%), medium (40-59%) and high (>60%) knowledge in red, amber and green respectively.

4.6 Discussion

To our knowledge, this is the first large-scale international study describing knowledge levels of contemporary CHO guidelines for competition by endurance athletes. Our current findings show 50 ±20% CEAC-Q total scores and subsection scores of ~10 ±5% with no differences between sections. We also identified that years of competitive experience, competitive level and a sports nutritionist influence are positively related to CEAC-Q scores. Importantly the CEAC-Q allowed to identify areas of high, medium and low knowledge of endurance athletes in different key knowledge areas of CHO for competition.

Our current findings (CEAC-Q score 50%, **Table 10**) corroborate our validation study (46% ±19%; **Chapter 3**) and support the idea that —on average— athletes only have moderate levels of knowledge and would highly benefit from quality educational resources to improve their theoretical knowledge. Until now it has been unclear how much endurance athletes know about current CHO guidelines, and whether recommended CHO intakes to be consumed within competition have been well translated, explained and understood, or require further clarification. We have identified topics that are well known to the majority of athletes as well as common gaps in knowledge that require further education and may partially explain why athletes consume suboptimal CHO within competition.

In contrast to Trakman et al. (2019b) who found no difference in knowledge between amateur and professional athletes, we observed notable increases in CEAC-Q score in athletes competing with more experience and at a higher level (**Table 10,** $p < 0.001$). Elite athletes may be more motivated to improve their nutritional knowledge and practice during competition due to greater pressure or expectation to perform and minimal margins between winning or losing (Trakman et al., 2016). Elite athletes are also less likely to use social media and online information for nutrition advice (Bourke, Baker and Braakhuis, 2019) and may also have greater access to a sports dietitian to provide them with nutrition advice which may partially explain their greater knowledge. Many studies have previously reported that athletes are hesitant to receive or seek help with their nutritional choices, instead preferring to rely on their own previous knowledge or self-directed research and social media for advice (Robins and Hetherington, 2005; Bourke, Baker and Braakhuis, 2019; McLeman, Ratcliffe and Clifford, 2019; Trakman et al., 2019b). Indeed, only 3% of runners and 5% of cyclists sought professional advice to guide their competition nutrition practices (Sparks et al., 2018; McLeman, Ratcliffe and Clifford, 2019). Athletes obtaining their nutrition information online may be accessing advice that is unreliable, unregulated or out of date resulting in lower CEAC-Q scores and knowledge gaps that influence suboptimal CHO intakes within competition.

The CEAC-Q identified that endurance athletes possess low understanding of CHO guidelines, with fewer than half able to correctly identify CHO guidelines for optimal intake when loading (**Table 11 Q8**, 28%), during (**Table 11 Q18abc**) or after competition (**Table 11 Q22**, 29%). These findings align with previous studies identifying poor knowledge of CHO guidelines in endurance athletes (Doering et al., 2016; McLeman, Ratcliffe and Clifford, 2019). It is plausible that this lack of knowledge could partially explain why many endurance athletes fail to consume optimal CHO during competition. It is yet to be determined how these knowledge gaps relate to CHO intakes within competition.

Our findings highlight that many endurance athletes lack knowledge of current CHO guidelines and are unable to identify the optimal CHO intakes to consume before, during and after competition. In practice the CEAC-Q can be used by sports dietitians to rapidly assess CHO nutrition knowledge and to identify knowledge gaps where endurance athletes require additional nutritional guidance and education. However, we do not yet know how knowledge of CHO guidelines as measured by the CEAC-Q is related to practice and whether the observed knowledge gaps can explain the mismatch previously observed.

4.7 Reflective pause (Study 2)

During this study I begun to see and visualise how my Professional Doctorate has, does and will continue to influence my practice as a sports dietitian. Halfway through the data collection I began using the CEAC-Q in my practice with new clients, sending their scores by email prior to our consultations. With the professional riders I worked with at Team Dimension Data the CEAC-Q helped to start conversations to build rapport and identify areas for future education or nutrition intervention. "*X. was consuming carbs at least 90 g.h at E3 Binck Bank. He said he'd never counted carbs before. 'Y' didn't fuel on the bike which caused him to blow up – though he doesn't want help. Then 'Z' also had the same issue – told me he is scared of eating carbs, especially in the lead up to the race and had less than 40 g.h (*1.4.2019)". These conversations also began to uncover potential barriers to fuelling optimally during competition to be explored in future studies *"talking about being unsure what to eat, when after a race. Or about knowing what to eat, but choosing not to, or getting overwhelmed by conflicting advice. Or how even kit design can make it too hard to get food out of the pockets if the jersey were too deep or when a race is chaotic* (4.4.2019)".

As I began use the CEAC-Q within practice, I gained confidence and began to see the value of using it with existing or future athletes, and how it could potentially be used as a business marketing tool. Participants were keen to receive feedback on the CEAC-Q "*he thought he would receive a score at the end, felt a bit disappointed that he didn't' get an answer when completing (*10.9.19)". Within my own business, having athletes complete the CEAC-Q and analysing their individual scores has led me to focus and structure how I develop educational resources be they blog posts, handouts, videos or podcasts. It allowed me to see how when interacting with athletes, CEAC-Q scores can guide I can how I provide valuable resources that are specific to their situation that may help motivate them to change their dietary behaviours.

It was interesting to observe that although the average CEAC-Q and subsection scores did not differ, there was a lot of variation within individual athlete scores. The CEAC-Q quickly identified gaps in CHO knowledge, and it was interesting to note that when providing feedback, some athletes reflected upon how this translated to their practice. As evident in **Figure 7**, this client identified that his recovery nutrition score was low, which may explain why he struggled with multiple stage events if he was not consuming adequate CHO to recover rapidly. Although this was not measured as part of my research, my hope was that having completed the questionnaire and identified that gap, he would then go on to do his own self-directed research, learn and change his practice to help him improve his performance in the future.

Re: CEAC-Q race nutrition survey results

MB

Tuesday, 4 February 2020 at 15:48

Show Details

You replied to this message on 04/02/2020, 15:52. Show Reply

Thanks Gemma
Really interesting as most of my own research has been about before and during comp which is very much reflected in my scoring!
My poor post comp might explain why multi day events are tough lol

Cheers

Sent from my iPhone

On 4 Feb 2020, at 14:23, Miss Gemma Sampson <gemma@dietitianwithoutborders.com> wrote:

Dear

Thank you for filling out the CEAC-Q Carbohydrates for Endurance Athletes in Competition questionnaire! Your responses are summarised below.

Total Score:	57.3 /100
Section 1. Carbohydrate storage and metabolism	10 /20
Section 2. Pre-event carbohydrate loading	12 /20
Section 3. Before-competition carbohydrate meal	16 /20
Section 4. Carbohydrate during competition	15.3 /20
Section 5. Carbohydrate for post-competition recovery	4 /20

I am currently developing suitable educational materials and resources to go alongside the questionnaire to help you make better nutritional choices during racing and competition. In the mean time, you may find the following blog posts and articles helpful to read:

Figure 7. CEAC-Q Feedback email and athlete response identifying recovery nutrition knowledge gaps that may explain relate to practice in multi-day events

Chapter 5

An assessment of the relationship between knowledge of carbohydrate guidelines and intake of endurance athletes before and during competition.

(Study 3)

5.1 Research orientation Study 3

For the first 4 months of data recruitment within this point in the Professional Doctorate, I was working part-time as a sports nutritionist for Team Dimension Data professional cycling team, transitioning back into private practice and opening a physical sports nutrition clinic in Girona. The purpose of this study was to measure if there was any relationship or association between what an athlete knows about CHO guidelines for optimal competitive performance and what they consume in practice during real-world competition. During the validation test-retest a surprising finding was that the act of completing the CEAC-Q resulted in a learning effect, allowing athletes to identify gaps in their own knowledge, which could potentially motivate them to change their practice. So as not to influence dietary intake during competition, the CEAC-Q was intentionally provided the after the race to minimize changes on behaviour.

5.2 Abstract

Purpose: Endurance athletes have moderate knowledge of CHO guidelines which may explain why many fail to achieve recommended CHO within competition. This study assessed the relationship between knowledge of CHO guidelines and dietary intake within endurance athletes in a real-world competition setting.

Methods: Amateur and professional athletes (n = 50) competing in international cycling, triathlon and running events recorded dietary intake for the 24 h period before competition (CHO load) and pre-competition meal using Remote Food Photography Method, with intake during collected by recall immediately after competition. The CEAC-Q assessed knowledge of guidelines for CHO loading (9 - 12 $g \bullet kg^{-1}$), the pre-competition meal (1 - 4 $g \bullet kg^{-1}$) and CHO during competition (60 - 90 $g \bullet h^{-1}$) for events >2.5 h in duration. Correlations between CHO knowledge and intake were analysed using Pearson correlation coefficient and Spearman's rank-order correlation.

Results: Correct knowledge of current guidelines was shown by 36% (n = 18) of athletes for pre competition day CHO loading and 64% (n = 32) for CHO intake during events. In relation to practice, 84 % (n = 42) athletes failed to achieve pre-competition day CHO intake guidelines by ingesting 6.5 ±2.2 $g \bullet kg^{-1}$ and 68% (n = 34) failed to achieve CHO intake during competition guidelines by ingesting 52 ±2 $g \bullet h^{-1}$. No association was evident between knowledge of CHO guidelines and dietary intake for CHO loading, the pre-event meal or during competition.

Conclusion: While some athletes are able to correctly identify CHO guidelines, no association was evident between knowledge and practice within competition. Qualitative studies exploring factors influencing the lack of association between knowledge of guidelines and intake during competition are required to further explain why knowledge is not translated into practice.

5.3 Introduction

As identified in **Chapter 4**, endurance athletes have moderate knowledge of CHO guidelines which may in part explain why many fail to achieve recommended CHO intakes for competition (Black, Skidmore and Brown, 2012; Spronk et al., 2015; Masson and Lamarche, 2016; Heikura et al., 2017b). These suboptimal CHO intake practices may be due to lack of knowledge, limited practical skills, physiological limitations (e.g. gastrointestinal distress), personal beliefs about CHO or a combination of factors (Heaney et al., 2008).

Lack of knowledge of CHO guidelines may be the primary factor given runners and triathletes are documented to lack general nutrition knowledge (Doering et al., 2016; McLeman, Ratcliffe and Clifford, 2019). In support of this, we recently identified that endurance athletes in general have limited knowledge of CHO guidelines for competition practices (**Chapter 4**) using a novel questionnaire (**Chapter 3**). While it is logical to assume a strong relationship between knowledge and practice, there is a paucity of literature evaluating the association between knowledge of current CHO guidelines and dietary habits of athletes during real-world competition. Under this hypothesis, athletes who lack sports nutrition knowledge would be less likely to adequately fuel themselves before, during or after training and competition, potentially compromising their performance (Havemann and Goedecke, 2008; Black, Skidmore and Brown, 2012; Spronk et al., 2015; McLeman, Ratcliffe and Clifford, 2019). However, the link between knowledge of CHO intake for competition and practice is yet not characterised.

The primary aim of this study was thus to determine the association between knowledge and dietary practice of contemporary CHO guidelines in a cohort of endurance athletes in a real-world competition setting. We hypothesised that athletes with superior CHO nutrition knowledge would closely follow CHO guidelines for optimal performance prior to and during competition.

5.4 Methods

5.4.1 Overview of experimental protocol

This was an observational study to explore the association between CHO knowledge and practice of endurance athletes during competition. CHO knowledge was assessed using the CEAC-Q which was completed the day after competition. Dietary intake was recorded 24 h prior to, the meal before using the Remote Food Photography Methodology (RFPM) and during competition by dietary recall (**Figure 8**). Participants then partook in a semi-structured interview 10 -14 days later to further investigate factors influencing the relationship between knowledge and practice (**Chapter 6**). No attempt was made to influence or alter race nutrition practices throughout the course of this study. The study was approved by the Ethics Committee LJMU [19/SPS/026].

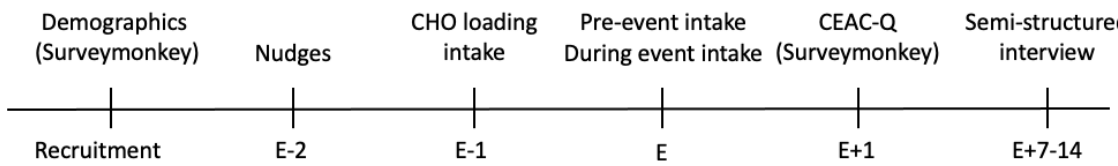


Figure 8 Study timeline from recruitment to semi-structured interviews.
Following recruitment, dietary intake was collected the day prior to, the meal before and during event (E), with carbohydrate (CHO) knowledge assessed using Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q). Nudges reminded participants to record dietary intake.

5.4.2 Participants

Amateur and professional endurance athletes registered to compete in national and international UCI cycling, Challenge Family, Ironman® triathlon and marathon running events between September 2019 and January 2020 were invited to participate through posters shared on social media. Participants provided informed consent and demographic data online using SurveyMonkey (https://www.surveymonkey.com, San Mateo, California, USA). Performance data regarding finishing time for each athlete was published on the event organisers official website shortly following the event and recorded for analysis.

5.4.3 Dietary intake collection and analysis of nutrient intake

Dietary intake was recorded for all food and fluids consumed in the 24 h period before competition day (CHO load) and the morning before competition (CHO pre-competition) using RFPM (Martin et al., 2009; Costello et al., 2017; Stables et al., 2021) Each participant was debriefed on the requirements of this methodology and nudged daily to send food photographs by phone to the lead researcher in real-time using WhatsApp Messenger (Facebook, Inc, Menlow Park, California) together with any relevant details of brand labels, cooking methods and description of ingredients (Martin et al., 2009; Costello et al., 2017). Due to the nature of the events and incapacity to report food intake during competition (CHO during), a retrospective food recall was conducted with each participant immediately after the event.

Dietary information was analysed through Nutritics software (Nutritics, LTD, Dublin, Ireland) summarised as total amounts (g) and intake relative to body mass ($g{\bullet}kg^{-1}$) or per hour of competition ($g{\bullet}h^{-1}$). Triathletes and runners reported any cups of fluid collected during the race while running past feed zones. The volumes of cups collected during competition were estimated as 150ml, the maximum volume of fluid likely to consume in a real-life running race (Burke et al., 2005). All dietary supplements and foods consumed were analysed according to manufacturer product labels or website dietary information. Prior to nutritional analysis, initial pilot testing was conducted to compare estimated portion sizes of various photographed foods and meals to their weighed counterpart (not recorded) to improve accuracy in using photographs to estimate portion sizes.

5.4.4 Carbohydrate knowledge and comparison to intake

CHO knowledge was assessed and scored using the Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q) as described in Chapter 3 (**Appendix 1**). The CEAC-Q was completed using SurveyMonkey the day following the event so as not to influence dietary choices. Only 3 subsections and questions (**Appendix 2**, Q8, 11, 18c) assessing knowledge of CHO guidelines were directly comparable to collected dietary intake, namely Section 2 CHO Loading (9 - 12 $g{\bullet}kg^{-1}$), Section 3 Pre-competition CHO meal (1 - 4 $g{\bullet}kg^{-1}$) and Section 4 CHO during competition (60 - 90 $g{\bullet}h^{-1}$) for events >2.5 h in duration. CHO intake was compared to total CEAC-Q score, relevant subsection score and knowledge of current guidelines.

5.4.5 Data analysis

Athletes who did not finish their race were removed from the analysis. Data were screened for missing values, outliers, normality and skewness. One-way ANOVA analysed differences between groups in continuous variables and X^2 test was applied to compare between groups for categorical variables. Correlations between total CEAC-Q score, CEAC-Q subsection scores, CHO guidelines and CHO intake at each time point were analysed using Pearson correlation coefficient for interval and Spearman's rank-order correlation for ordinal data. All statistical analyses were conducted using IBM SPSS version 26 software (IBM Corp., Armonk, NY) with results reported as mean ±SD with a significance level of $p < 0.05$.

5.5 Results

5.5.1 Participant characteristics

The study cohort comprised of 50 endurance athletes (male n =13, female n =37) who competed in organised cycling (n =17), triathlon (n =29) and running (n =4) events at an amateur (n =21) or professional (n = 29) level. Events consisted of one-day cycling (UCI World Championships Harrogate, Vuelta CV Feminas, L'Etape Australia, 50-mile TT) and multi-stage cycling races (Tour of Tasmania); 70.3 triathlon (Western Sydney, Taupo, Indian Wells, Bahrain, Challenge Daytona), Ironman® triathlon (Western Australia, Wales, Lanzarote, Cozumel, Arizona) and marathon running (Frankfurt, Valencia, Malaga). Mean duration was >150 minutes for all 19 events; one-day (n = 4; 225 ±69) and multi-stage cycling (n = 1; 169 ±8); 70.3 half Ironman® triathlon (n = 5; 245 ±44) and full Ironman® triathlon (n = 5; 552 ±88) and marathon (n = 3; 174 ±30). Over half (n = 29, 58%) of athletes had previously worked with a sports dietitian, with demographic data summarised in **Table 12**.

Table 12. Characteristics of athletes and CEAC-Q score by competitive level, gender and sport

		Competitive level		Gender		Sport		
	All (n = 50)	Amateur (n = 21)	Professional (n = 29)	Male (n = 13)	Female (n = 37)	Cycling (n = 17)	Triathlon (n = 29)	Running (n = 4)
Age (y)	29.2 ±6.5	26.7 ±6.1	31.0 ±6.3	25.5 ±4.1	30.5 ±6.8	24.9 ±5.3	31.3 ±6.2	32.5 ±5.3
Mass (kg)	61.4 ±8.6	60.7 ±9.5	61.9 ±8.0	72.0 ±6.8	57.6 ±5.5	59.4 ±7.5	62.9 ±9.4	59.0 ±6.4
CEAC-Q	55 ±15	55 ±17	55 ±13	56 ±18	54 ±14	58 ±14	53 ±15	48 ±20

Differences in CEAC-Q scores between cyclists (58 ±14 %) triathletes (53 ±15 %) or runners (48 ±20 %) did not reach significance (p = 0.363). No difference in CEAC-Q scores were observed between amateur or professional (55 ±17, vs 55 ±13%, p = 0.961), male or female (56 ±18 vs 54 ±14%, p = 0.680) or athletes who worked with a nutritionist or not (53 ±16 vs 56 ±15%, p = 0.419).

Table 13. Knowledge of carbohydrate guidelines, actual intake within competition and correlation.

Knowledge of CHO Guidelines (CEAC-Q)			CHO intake within competition		Correlation	
CEAC-Q Question	**CEAC-Q guideline Intake responses**	**N (%)**	**Total (g)**	**g•kg^{-1} (g•h^{-1})**	**Spearmans coefficient**	**P**
CHO Loading (Q8) When carbohydrate loading before competition, the recommended range of carbohydrate intake per day is?	5 - 8 g•kg^{-1}	7 (14)	428 ±157	6.6 ±2.5	0.133	0.358
	9 - 12 g•kg^{-1}†	18 (36)	389 ±142	6.1 ±1.9		
	>12 g•kg^{-1}	2 (4)	339 ±108	5.5 ±0.1		
	CHO loading never required	2 (4)	312 ±56	6.1 ±1.3		
	Unsure	21 (42)	403 ±132	6.9 ±2.4		
CHO pre-race meal (Q11) How much carbohydrate should a meal eaten before competition contain?	< 1 g•kg^{-1}	1 (2)	46	0.8	0.101	0.487
	1 - 4 g•kg^{-1}†	19 (38)	87 ±37	1.4 ±0.6		
	>4 g•kg^{-1}	9 (18)	115 ±46	1.7 ±0.6		
	Unsure	21 (42)	87 ±30	1.5 ±0.5		
CHO during (Q18c) How much carbohydrate is recommended per hour during competition lasting >2.5h duration:	30 – 60 g•h^{-1}	9 (18)	226 ±173	(53 ±22)	0.028	0.849
	60 – 90 g•h^{-1}†	32 (64)	341 ±245	(56 ±20)		
	>90 g•h^{-1}	4 (8)	150 ±126	(32 ±9)		
	Unsure	5 (10)	183 ±162	(41 ±15)		

Athlete reported knowledge of CHO guidelines intakes for each time point obtained from responses to CEAC-Q questions Q8: CHO Loading; Q11: CHO pre-competition; 18c: CHO during >2.5h duration; and subsequent CHO intake. †CHO Guideline

5.5.2 Knowledge of carbohydrate guidelines (CEAC-Q scores)

Mean total CEAC-Q score was 55 ±15 % (range 23-86%), with no difference between relevant subsection scores; Section 2: CHO Loading (11 ±5), Section 3: CHO Pre-event (12 ±4) and Section 4: CHO during (11 ±5). A third of athletes knew that recommended CHO loading intake was 9 - 12 g•kg^{-1} (**Table 13 Q8**; n = 18, 36%) and that a pre-competition meal should contain 1 - 4 g•kg^{-1} CHO (**Table 13 Q11**; n = 19, 38%). Whereas two thirds of athletes knew that during events >2.5 h in duration CHO should be consumed at a rate of 60 - 90 g•h^{-1} (**Table 13 Q18c**; n = 32, 64%).

5.5.3 Carbohydrate loading intake consumed 24 h prior to competition

The majority of athletes failed to meet CHO guidelines for CHO loading (**Table 14**, **Figure 9A**, 84%), with intakes of 9 - 12 g•kg^{-1} only achieved by 8 athletes (**Table 14, Figure 10A,** 16%) with mean intakes of 6.5 ±2.2 g CHO.kg (range 2.9 - 11.9 g•kg^{-1}) ranging between 185 and 678 g (395 ±134 g). While professional athletes consumed 105g more CHO than amateur athletes (439 ±122 vs 334 ±130 g, p = 0.005), both failed to achieve CHO loading recommendations (7.2 ±2.0 vs 5.6 ±2.0 g•kg^{-1}, p = 0.008). Similarly, while male athletes consumed 84 g more CHO than females on average (457 ±143 vs 373 ±126 g, p = 0.052), there were no differences in CHO intake relative to body mass (6.4 ±2.2 vs 6.5 ±2.2 g•kg^{-1}, p = 0.908) and, on average, neither reached the CHO loading intake recommendations. For each timing there was a remarkable inter-individual variation in actual CHO intakes (**Figure 10**).

5.5.4 Pre-competition meal carbohydrate intakes

The pre-competition meal consumed by athletes contained 91 ±37g (34-197g) CHO with relative intakes of 1.5 ±0.6g CHO.kg^{-1} (0.5-2.6 g•kg^{-1}). While the majority of athletes (n = 40, 80%) met minimum CHO recommendations of 1 - 4 g•kg^{-1} (**Table 14**), 10 consumed <1 g•kg^{-1} in the meal before their event (**Figure 9B,** 20%).

5.5.5 During competition carbohydrate intakes

Mean CHO intake during competition was 52g ±20 g•h^{-1} with just a third (n =16, 32%) of athletes consuming optimal CHO for events lasting >2.5h in duration (60 - 90 g•h^{-1}) and 2 consuming >90 g•h^{-1}). The majority of athletes consumed suboptimal CHO during competition (**Table 14**, **Figure 9C**, 68%), with 8 athletes (16%) consuming very low CHO intakes <30 g•h^{-1}. Intake ranged from 15-102 g•h^{-1} with wide variation between events (**Figure 9C**) and individual athletes (**Figure 10C**). Marathon runners consumed considerably less CHO per hour (32 ±10 g•h^{-1}) than cyclists (48 ±23 g•h^{-1}) or triathletes (55 ±19 g•h^{-1}, p = 0.005). Professional athletes consumed considerably more CHO per hour during competition than amateurs with intakes more aligned with guidelines for competition >2.5h (61 ±19 vs 40 ±15 g•h^{-1}, p <0.001).

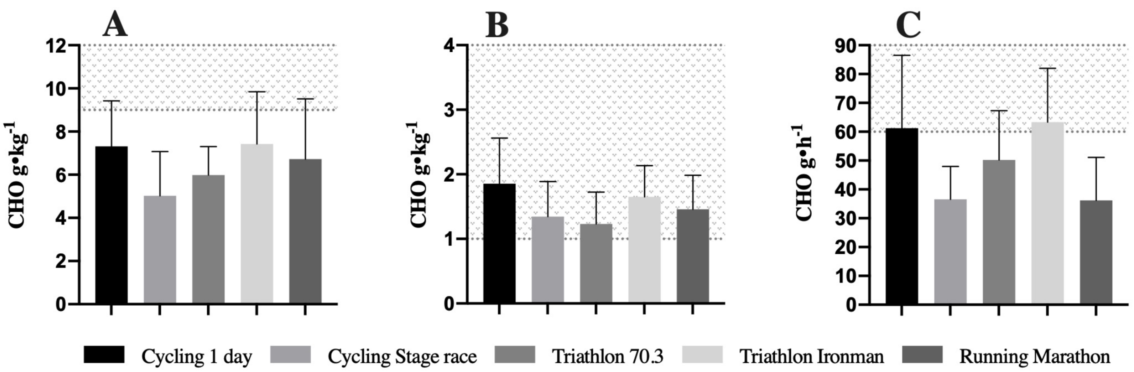


Figure 9. Mean carbohydrate intakes of endurance athletes according to event and guidelines.
CHO intakes in relation to CHO guidelines vary between sporting events. The dotted lines in each panel indicate the recommended amounts specific for the timing: **A**) Optimal CHO loading intake 9 - 12 g•kg.bm^{-1}, **B**) Optimal CHO intake pre-competition 1 - 4 g•kg•bm^{-1}, **C**) Optimal CHO intake during competition 60 - 90 g•h^{-1}

Table 14. Proportion of athletes achieving carbohydrate guidelines during competition

	CHO intake within competition (g)	g•kg^{-1} (g•h^{-1})	CHO Guideline	Proportion met guideline n (%)
CHO loading	395 ±134	6.5 ±2.2	9 - 12 g•kg^{-1}	8 (16)
CHO pre-event meal	91 ±37	1.5 ±0.6	1 - 4 g•kg^{-1}	40 (80)
CHO during competition	289 ±226	(52 ±21)	60 - 90 g•h^{-1}	16 (32)

Mean total and relative CHO intakes in relation to CHO loading 24 h prior to competition, CHO consumed in the pre-event meal or CHO consumed during competition and the proportion of athletes achieving CHO guidelines.

5.5.6 No relationship between carbohydrate knowledge and practice

No relationship was observed between knowledge of guidelines for CHO loading, pre-event meal or during competition and corresponding CHO intake of athletes as summarised in **Table 13**. Total CEAC-Q score was not associated with intake for CHO loading ($p = 0.677$), CHO pre-competition ($p = 0.0563$) or CHO during competition ($p = 0.88$). Neither did any correlation exist between CHO intake 24 h prior to competition and subsection 2 score (CHO loading; $p = 0.281$); CHO intake in the meal before competition and subsection 3 score (pre-competition meal; $p = 0.85$) or CHO intake during event and CEAC-Q subsection 4 score (CHO during; $p = 0.059$).

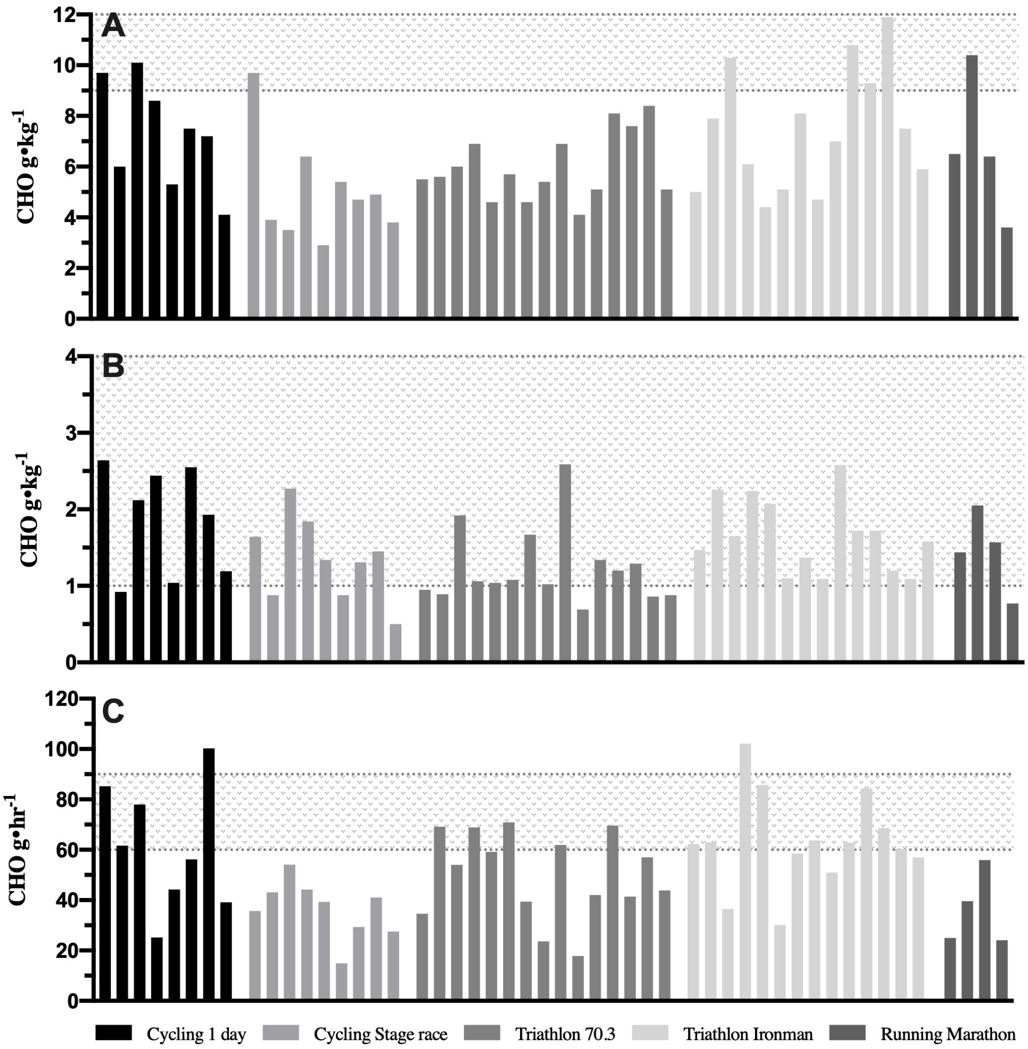


Figure 10. Individual athlete carbohydrate intake by event throughout real-world competition

Each column represents an individual athlete intake compared to recommended intakes, grouped by the event competed in. Dotted lines represent CHO guidelines for each timepoint whereby A) CHO load 9 – 12 $g \cdot kg \cdot bm^{-1}$; B) CHO pre-competition 1 - 4 $g \cdot kg \cdot bm^{-1}$; C) CHO during 60 - 90 $g \cdot h^{-1}$

5.6 Discussion

The main finding of this study is that we found no relationship between knowledge on CHO for competition and practice. To the best of our knowledge this is the first study using a validated nutrition knowledge questionnaire concomitantly addressing knowledge and dietary practice in athletes in relation to CHO intake for competition. This allows us to identify that theoretical knowledge on its own is not directly reflected in practical real-world outcomes. While we observed that some endurance athletes are able to identify current CHO guidelines, they do not consistently apply this knowledge into practice, particularly in relation to CHO loading and optimal intake consumed during competition. Our findings are important to allow sports dietitians to identify and address the limiting factors influencing suboptimal dietary practices of endurance athletes in competition

Our intervention was delivered in a ‘free-living’ context with athletes recording intake using RFPM prior to, and dietary recall immediately post real-world competition making this a highly ecologically valid applied approach to assess practice against athletes’ knowledge. Assessing dietary intake in conjunction with the CEAC-Q to identify knowledge gaps of CHO unravels a new frontier in the link between knowledge and practice. Gaps in knowledge and practice of CHO loading and intake during competition clearly exist within endurance athletes. CHO knowledge as measured by total CEAC-Q score of 55%, was in line with scores previously observed in Chapter 4. As evident in **Table 13**, knowledge of CHO guidelines did not directly translate into practice for CHO loading or intake during competition. While 36% of athletes correctly identified 9 - 12 $g•kg^{-1}$ as optimal for CHO loading, their CHO intake the day before competition did not differ from the athletes who were unsure (**Table 14,** 6.1 ±1.9 vs 6.9 ±2.4 $g•kg^{-1}$, $p = 0.358$). Our findings align with those observed by Havemann and Goedecke (2008) where CHO intake of cyclists did not differ between those who reported to CHO load and those who did not (6.0 vs 5.6 $g•kg^{-1}$). Likewise, while a greater proportion of athletes (64%) correctly identified the CHO guidelines of consuming 60 - 90 $g•h^{-1}$ during competition, actual intake of 56 ±20 $g•h^{-1}$ fell short of this target on average in this group of individuals (**Table 14**). Opposite to these observations, several athletes (42%) were unable to correctly identify the pre-event CHO recommendations in the CEAC-Q, yet their intake of 1.5 ±0.5 $g•kg^{-1}$ fell within the guidelines (**Table 13**). From these observations it can be concluded that knowledge may be a facilitator, but it seems evident that actual dietary choices are strongly influenced by factors other than theoretical knowledge.

Beyond knowledge of CHO guidelines, poor nutritional adherence during competition may be influenced by personal beliefs and external factors including regulations dictating when athletes are allowed to consume or collect food and fluids mid-race, access to food at feed station, race tactics or extreme weather conditions (Ebert et al., 2007; Wardenaar et al., 2015; Heikura et al., 2017a; Thurecht and Pelly, 2019; Thurecht and Pelly, 2020). Indeed, one study reported that 52% of amateur cyclists did not intend to CHO load prior to their race because they believed they did not need it or feared gaining weight (Sparks et al., 2018). Whereas athletes who did intend to CHO load failed to consume optimal intakes, perhaps due to insufficient knowledge and practical skills of the food required to achieve this (Atkinson et al., 2011). As knowing the CHO guidelines does not consistently relate to practice, our findings indicate that behaviour change approaches used by sports dietitians may need to focus on factors beyond improving knowledge of CHO guidelines.

Knowledge of CHO guidelines does not necessarily translate into athletes achieving them in practice. The COM-B model of behaviour change suggests that an athlete must have the Capability, Opportunity and Motivation to change their Behaviour (Bentley et al., 2021) and must be ready for, want to, and able to make that change (Bartlett and Drust, 2020). Thus to consume CHO in alignment with guidelines, athletes must have the knowledge and skills (capability), the social and physical opportunity and motivation to consume that CHO in the presence of competing behaviours (Michie, van Stralen and West, 2011). Dietary intake during competition may be influenced by a range of factors (Heaney et al., 2011; Pelly and Wright, 2021). Deeper understanding is required of all factors influencing the ability of endurance athletes to apply nutritional knowledge of these guidelines into practice to enable them to make the best dietary choices within competition (Pelly and Wright, 2021).

In conclusion, CHO loading intakes of endurance athletes during the 24-hour period prior to and during competition are lower than current recommendations. While some athletes are able to correctly identify CHO guidelines for competition, no association was evident between knowledge and practice. Qualitative studies exploring factors influencing the lack of association between knowledge of CHO guidelines and intake within competition are required to further explain why knowledge is not translated into practice. This information will lead to an improved understanding of what drives dietary habits of endurance athletes during competition so that sports dietitians may provide better nutritional support and education to optimise intake and performance.

5.7 Reflective pause (Study 3)

Reflecting over the way my research has evolved to this point, my initial intention had been to measure how effective I was as a practitioner, and how I can influence dietary behaviours of athletes. However, I realised that my research focus was moving towards assessing what athletes know, what they believe, perceive, their attitudes and how they influence dietary practice. If we don't know the reasons why athletes do or don't do something (despite the evidence), then we aren't going to be able to have much impact on changing their behaviour.

I identified further resistance doing something I wasn't confident in (analysing food photographs) "*partly because I know how small discrepancies can make a huge impact – was remembering my research from UOW on food photography portion sizes where micronutrients a small difference made a huge impact. The same would be said for energy and carbs. Say I estimate someone has eaten 150g of carbs, when they actually ate 175g – that means a difference of 2.14 g.kg vs 2.5g.kg for a 25g carb difference. I feel like a I need to do some validation work here to justify, compare weighed food diaries to food photographs*." (18.6.19). Following on from the previous learnings that confidence comes with action, prior to recruitment I did conduct trials at home visually estimating portions of CHO foods then weighing them to determine the difference, and conducted pilot trials with current clients, "*I started doing RFPM with X today. I don't know why I was so worried! It's not as difficult as I was making it out to be.. It's important for me to brush up on my food portions, both estimating and measuring them. I estimated that a cup of couscous was 200g – and now I've gone and weighed measured couscous and ½ cup dry was 95g and ½ cup cooked was 110g so pretty close*!" Prior to completion of this thesis, a validation study was published that demonstrates that experienced sports nutritionists using RFPM underestimate daily CHO intake by -53.4g and individual meals by -11.5g (Stables et al., 2021). This provided confidence in my data because I determined that accounting for this potential error in dietary analysis, this cohort of athletes would still fail to achieve minimum recommendations the day prior to competition.

Learning to use the Remote Food Photography Method for this study gave me the confidence using this technique in my professional practice with athletes to obtain food diaries.

Evaluating my first 6 months working in elite high-performance sport, I read an interesting article on sports nutritionists' perspectives on enablers and barriers to adherence using the COM-B model that jumped out about trying to do too much to prove myself. '*an inexperienced sports nutritionist would typically overdeliver because want to be seen doing a good job and experience comes the art of managing what is feasible and what is realistic*" (Bentley et al., 2019). I learnt a lot working in professional cycling in 2019, but in hindsight I was overcommitted with my time and energy and was trying to juggle too many responsibilities. However, it did open many doors professionally, and gave me many opportunities to use my research with professional athletes "*I had a question specific to CHO loading from an athlete from TDD last night, so I asked him to fill out the CEAC-Q. His score was high (70%), and he had a general idea of what to do but then putting it in to practice was where he struggled. Having his responses as a starting point when having conversations means I am really able to pinpoint my time, effort and energies on what is most important to supporting relevant change in that person. I am finding the CEAC-Q is such a valuable tool within my own practice as a sports dietitian.* (17.1.20)"

Chapter 6

An exploration of factors influencing the lack of association between knowledge of carbohydrate guidelines and intake within competition; towards the COM-B model of behaviour change.

(Study 4)

6.1 Research orientation Study 4

The purpose of this study was to identify any patterns and themes in the behaviour, beliefs and knowledge of endurance athletes or barriers that influenced intake of CHO during competitive periods that may explain the mismatch observed between recommendations and practice. Through prior discussions with athletes I identified many potential factors that influence why they chose to eat (or not) at an amateur and professional level "*chatting with X from Canyon-SRAM about my research and she was saying how other riders on her team intentionally won't eat carbohydrate before or during a race if there is say a hill climb in it, because they don't want to carry the weight and they want to be lighter – so they are [intentionally] under-fuelled during the race* (22.9.19)". As I am usually paid to provide nutrition advice that provides results, I was inherently aware that any pre-conceived ideas and the manner in which I conducted interviews could lead the direction of the conversation. I aimed to minimise this bias to the best of my ability and first conducted pilot test interviews athletes to support this "*I identified that when talking with the athlete I wanted to provide advice, to help and give them a new perspective or something to walk away with that benefitted them. When I'm conducting research this is something that I will have to be wary of in particular to reflexivity and how I influence the data by either encouraging, showing sympathy or asking leading questions (12.7.19)*."

When data collection commenced, I was employed part-time by a professional cycling team. After my contract ended mid-data collection I returned to my private practice at the start of 2020 and fortunately data collection was complete before COVID-19 hit and all endurance events were cancelled. COVID-19 had a direct impact on my business and practice with much work lost during this period. I was living in Spain which went into a strict lockdown for 8 weeks during which we were not allowed to leave our house. Although financially challenging, the lost work granted me a unique opportunity of time, which I used wisely to transcribe the interviews I had conducted and become thoroughly immersed in the data. Data analysis beyond this point took a further 10 months while restructuring my business throughout a pandemic and trying to condense an extremely large and interesting dataset.

6.2 Abstract

Purpose: While some endurance athletes can identify current carbohydrate (CHO) guidelines, little is known about why this knowledge is not consistently translated into practice within competition. This study explored factors that explain the lack of association observed between knowledge of CHO guidelines and actual CHO intakes of endurance athletes within competition.

Methods: Semi-structured interviews were conducted in 50 amateur and professional endurance athletes 7 - 14 days post-competition who had previously failed to meet CHO guidelines for competition. Interview transcripts were first analysed inductively line-by-line using thematic analysis. A deductive approach then applied the COM-B model of behaviour change as a coding framework to inform a position of all factors influencing the *capability, opportunity* and *motivation* of endurance athletes to apply knowledge to dietary practice 24 h before and during competition.

Results: Thematic analysis generated 3 higher order themes providing consensus explaining the lack of association observed between knowledge and dietary practice amongst athletes; namely low *capability* (knowledge, skills and confidence) to apply CHO loading protocols, low *motivation* to practice CHO loading (beliefs and fears) and external factors that limit the *opportunity* to consume planned CHO during competition (weather, intensity and regulations).

Conclusion: Endurance athletes did not achieve CHO loading guidelines due to low knowledge and skills, or personal beliefs and fears that limited intake. Conversely, despite knowing CHO guidelines during competition, athletes were frequently exposed to external factors during competition that limited the ability to consume planned CHO intake. Once the key limiting factors between knowledge and practice are identified through motivational interviewing, they can be suitably addressed via targeted nutrition education, interventions and behaviour change techniques.

6.3 Introduction

CHO loading and during competition intakes that fail to achieve guidelines have been frequently observed in endurance athletes within my practice and in real-world competition (Heikura et al., 2017b; Sparks et al., 2018; McLeman, Ratcliffe and Clifford, 2019). As shown in the literature review and further emphasized with the results of Chapter 5, CHO intakes of endurance athletes during the 24-hour period prior to (CHO loading) and during competition are lower than current recommendations. While some athletes are able to correctly identify CHO guidelines for competition, no association was evident between knowledge and practice. Whether this mismatch exists primarily because athletes are *unaware* of the current guidelines for CHO, experience difficulties with *translation* of knowledge into practice or have *personal beliefs* which influence under-consumption during competition is something that quantitative analysis of data was unable to determine.

Clear gaps in knowledge of current CHO guidelines were identified using the CEAC-Q in **Chapters 4 and 5**, with no association evident between knowledge and practice during real-world competition. While 36% of endurance athletes correctly identified 9 - 12 $g.kg^{-1}$ for CHO loading, their CHO intake the day before competition failed to differ from the athletes who were unsure (**Chapter 5** **Table 13**, 6.1 ±1.9 vs 6.9 ±2.4 g, $p = 0.358$). Likewise, while 64 % of athletes knew to consume 60 - 90 $g.h^{-1}$ during competition, mean intake of 56 ±20 $g.h^{-1}$ fell short of this target (**Chapter 5** **Table 13**). Clearly, while knowledge may be a facilitator for athletes to consume CHO intakes that align with guidelines, knowledge alone is not enough, and other factors evidently influence translation to dietary intake and practice.

The link between general nutrition knowledge and behaviour is complex, influenced by factors including taste, food preferences, culture, religion, family beliefs, convenience, skills in shopping, food preparation skills, travel and personal beliefs (Heaney et al., 2008; Heaney et al., 2011). To translate knowledge of CHO guidelines into practice within competition, the athlete must be ready, want to and be able to change their dietary behaviour (Bartlett and Drust, 2020). The COM-B theoretical model suggests that in order for an athlete to engage in the targeted *Behaviour*; namely to achieve CHO guidelines before, during and after competition, they must have the psychological and physical *Capability* (knowledge and skills), the social and physical *Opportunity* and *Motivation* to consume that CHO in the presence of competing behaviours (Michie, van Stralen and West, 2011; Bentley et al., 2021). Little is known about factors influencing the relationship between competition specific sports nutrition knowledge, practices, beliefs and CHO intake within competition. Having a clear understanding of what drives dietary behaviours of endurance athletes in competition can allow sports dietitians to better facilitate the way in which they educate, translate knowledge and support behaviour change to optimise dietary intake of endurance athletes for competitive performance.

The purpose of this study was to explore factors that explain the lack of association observed between knowledge of CHO guidelines and actual CHO intakes of endurance athletes during real-world competition towards the COM-B model of behaviour change.

6.4 Methods

This observational study was a component within a greater project collecting quantitative (intake and knowledge) and qualitative (beliefs and barriers) as detailed in **Chapter 5**. Endurance athletes competing in international cycling (n = 17), triathlon (n = 29) and running (n = 4) events between September 2019 and January 2020. Given the exploratory nature of study, a qualitative approach was adopted to identify all factors that influence CHO intake within competition. The study was approved by the Ethics Committee LJMU [19/SPS/026].

6.4.1 Participants

The study cohort consisted of the same 50 endurance athletes (37 females, 13 males) competing at amateur (n = 21) or professional (n = 29) level from Study 3 (**Chapter 5**). Amateur athletes competed at national or international events, and professional athletes were licensed with the Union Cycliste International (UCI) or relevant triathlon federation for Ironman® and Challenge Family triathlons. Participants were anonymised, numbered and coded by sport (C = Cycling, T = Triathlon or R = Running), competition level (P = Professional, A = Amateur) and gender (M= Male, F = female), where **1CPF** represents athlete 1 who is a **C**yclist, **P**rofessional and **F**emale.

6.4.2 Data Collection

Information related to the experimental design, the events, CHO intake, nutritional intake, and CEAC-Q knowledge scores has been described in **Chapter 5**. In brief, in the greater project, participants recorded all food intake the day before competition (CHO loading) using the remote food photography method and during competition (CHO during) by dietary recall. The Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q) was completed the day post-competition to determine overall CHO nutrition knowledge score, identify specific gaps in CHO knowledge and provide qualitative comments **(Figure 11**).

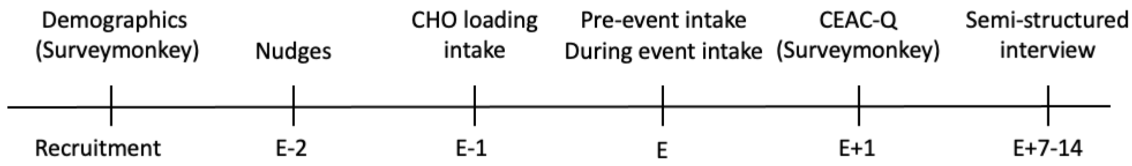


Figure 11 Study timeline from recruitment to semi-structured interviews.
Following recruitment, dietary intake was collected the day prior to and during event (E), with carbohydrate (CHO) knowledge assessed using the Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q). Semi-structured interview was completed 7 - 14 days post competition via videocall.

6.4.3 Semi structured interviews

Semi-structured interviews were conducted 7 - 14 days post-competition to explore competition nutrition practices and identify reasons behind any lack of association between knowledge of guidelines and actual CHO intake. Interviews covered five main questions 1) Describe what you do with your nutrition the day before a race; 2) What do you do for nutrition during a race; 3) What are your thoughts on carbohydrate loading; 4) What influences what you do or don't eat the day before and during a race; 5) How would you rate your nutrition knowledge? as directed by the interview guide (**Appendix 2**). Interviews were conducted individually to understand factors influencing dietary practices of athletes during competition independent of their peers. Interviews were recorded remotely using videocall software (Zoom Video Communications, Inc, San Jose, California) secure online video conferencing software which can be accessed using computer, tablet or smartphone, has end-to-end HIPAA compliant encryption for interviews with geographically dispersed participants (Matthews, Baird and Duchesne, 2018). Interviews lasted a mean 24 minutes (range 12 - 47 min) and were transcribed verbatim.

6.4.4 Data Analysis

Interview transcripts were uploaded into NVivo Software package (NVivo10 for Mac, QSP Int., Australia) to facilitate the analysis process, manage and organise data (Welsh, 2002). Reflexive thematic analysis was used to identify, analyse and report patterns within the interviews using a 6 phase approach that was flexible, but not linear (Braun and Clarke, 2006): 1) Familiarising with the data; 2) Generating initial codes; 3) Generating themes; 4) Reviewing themes 5) Defining and naming themes 6); Producing the report. Systematic line-by-line coding using an inductive approach first coded any segment of text with each transcript relevant to the research question to determine lower-order codes for classification resulting in 146 initial codes. Following inductive analysis, a deductive approach then applied the COM-B model as a coding framework, assigning codes according to whether they explained the capability, opportunity or motivation of athletes in relation to CHO loading intake or CHO intake during competition. As codes were modified, combined or added, these were reapplied to each transcript with a firm set of coding rules guiding the coding process. This informed a position of all factors influencing knowledge and dietary intake of endurance athletes regarding CHO, and how these interlink the *capability, opportunity* and *motivation* to apply knowledge to dietary practice 24 h before (**Appendix 3**) and during competition (**Appendix 4**). Evidence highlighting a single athletes' narrative is provided in the form of a verbatim quotation, with reference made to the number contributing to each subtheme.

6.4.5 Markers of quality

Thematic analysis qualitative research is about finding meaning, meaning-making and telling stories to interpret the data in its specific context, whereby themes are patterns of shared meaning underpinned by a core concept (Braun and Clarke, 2019a). As such key and noteworthy themes identified may not necessarily depend on quantifiable measures but instead whether they clearly capture or explain by consensus something important in relation to the overall research question (Braun and Clarke, 2006). As set out in the researcher positionality and orientation, when attempting to understand experiences, qualitative research and interpretation will always be informed by the researcher's unique assumptions, values, commitments and experience (Braun and Clarke, 2013; Smith and McGannon, 2017). Qualitative reflexive thematic analysis is therefore not about reaching complete consensus or following a series of clear steps (Trainor and Bundon, 2020), but instead about the researchers' engagement with the data, their reflexive, intentional and thoughtful engagement with the analytical process (Braun and Clarke, 2019a; Braun and Clarke, 2020).

To maintain a quality investigative and analytical process, the present study adhered to the best practice criteria proposed by Tracy (2010) for qualitative research: worthy topic, rich rigor, sincerity, credibility, resonance, significant contribution, ethics, meaningful coherence. Understanding the factors influencing CHO intake, and thus performance of endurance athletes during competition is a *worthy topic* that is relevant, timely, significant and interesting for sports dietitians (Tracy, 2010). Pilot interviews were conducted with three athletes (not included within the dataset) to refine and develop the research instrument thus providing *rich rigor* (Cresswell, 2018). To improve *credibility* and support an optimal level of competence, the primary researcher completed a period of training supervised by a researcher with experience in semi-structured interviews and qualitative analysis. Field notes and a reflexive journal were kept throughout data collection and analysis for *sincerity* and *resonance* and *ethics* to clarify interpretive views and process interaction during interviews, striving to be reflexive and interactive with the data themes and patterns. These were discussed and reflected upon during supervision meetings evaluating interview technique, transferable findings, the *significant contribution* of the data collected and *meaningful coherence* regarding how they fit within the current literature (Tracy, 2010).

6.5 Results

As previously demonstrated in Chapter 5, endurance athletes in this study failed to achieve recommended CHO intakes in two distinct periods; CHO loading 24 h prior to competition and CHO during competition. Thematic maps depicting all factors (facilitators and barriers) influencing CHO intake according to the COM-B model and TDF theoretical constructs available for reference in **Appendix 3 and 4**. Inductive and deductive thematic analysis generated 3 higher order themes providing consensus explaining the mismatch observed between knowledge and dietary practice amongst athletes; namely low *capability* (knowledge and skills) to apply CHO loading protocols (**Figure 12, Table 15**), low *motivation* to practice CHO loading (**Figure 13, Table 16**), and external factors that limit the *opportunity* to consume planned CHO during competition (**Figure 14**, **Table 18)**.

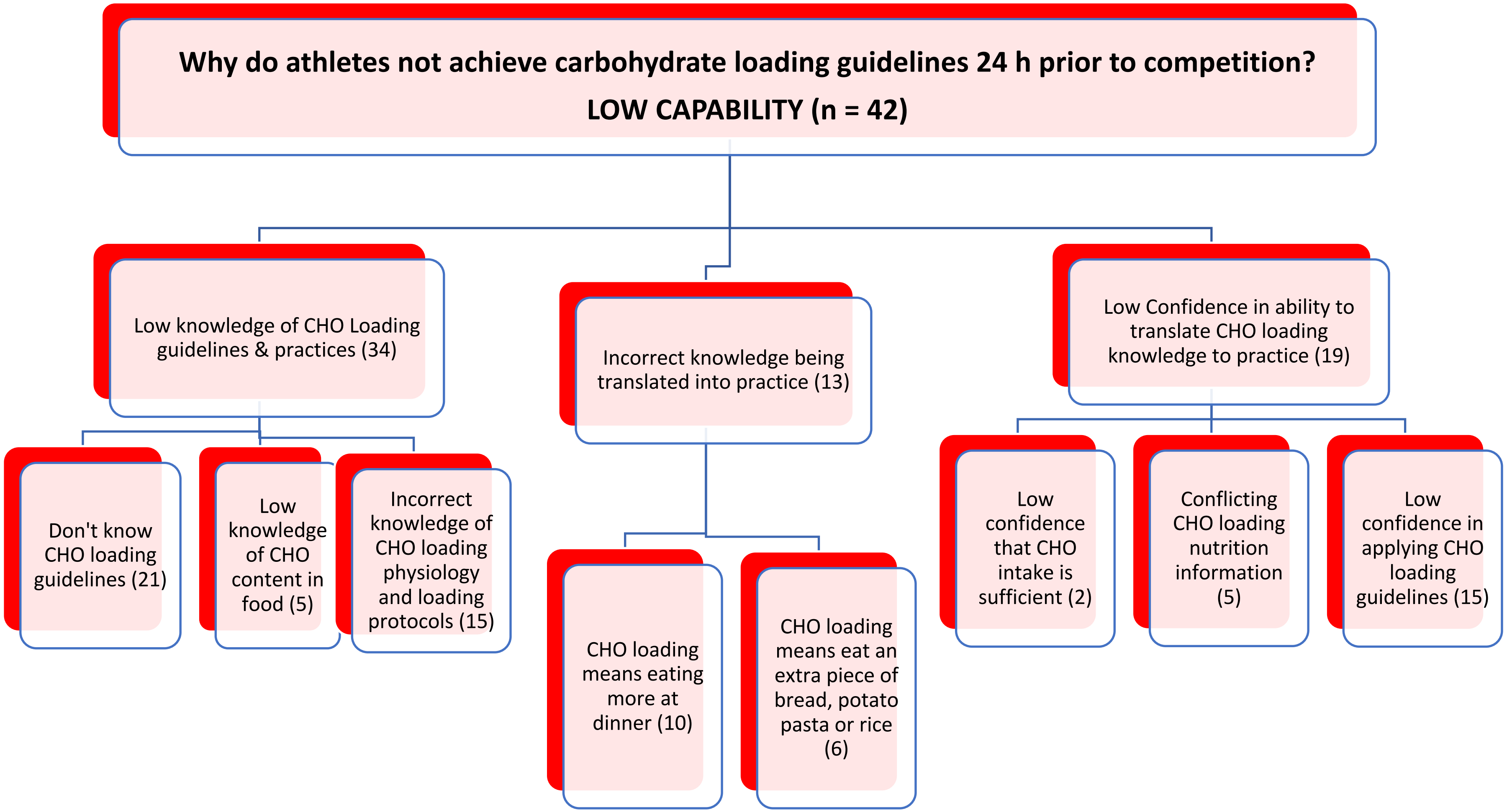


Figure 12. Endurance athletes reported low capability to meet carbohydrate loading guidelines 24 h prior to real-world competition

No association was observed between knowledge of CHO loading guidelines and practice in real-world competition. Reflexive thematic analysis using the COM-B model of behaviour change to explain this lack of association identified that 42 endurance athletes had low capability to CHO load due to low knowledge of guidelines and practices, incorrect knowledge being applied in practice and low confidence in ability to apply knowledge to practice

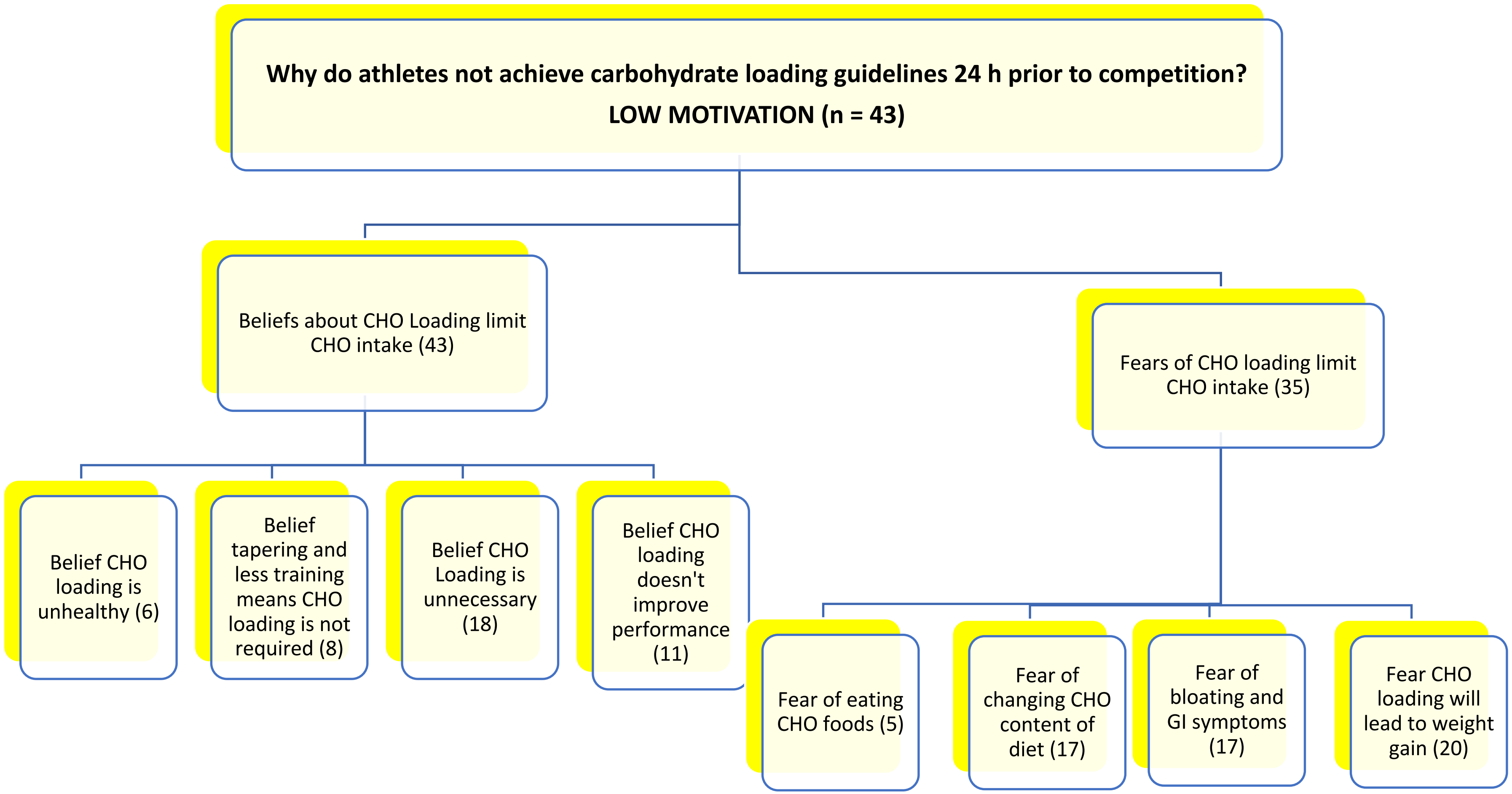


Figure 13. Endurance athletes reported low motivation to meet carbohydrate loading guidelines 24 h prior to real-world competition

No association was observed between knowledge of CHO loading guidelines and practice in real-world competition. Reflexive thematic analysis using the COM-B model of behaviour change to explain this lack of association identified that 43 endurance athletes had low motivation to engage in CHO loading due to personal beliefs and fears.

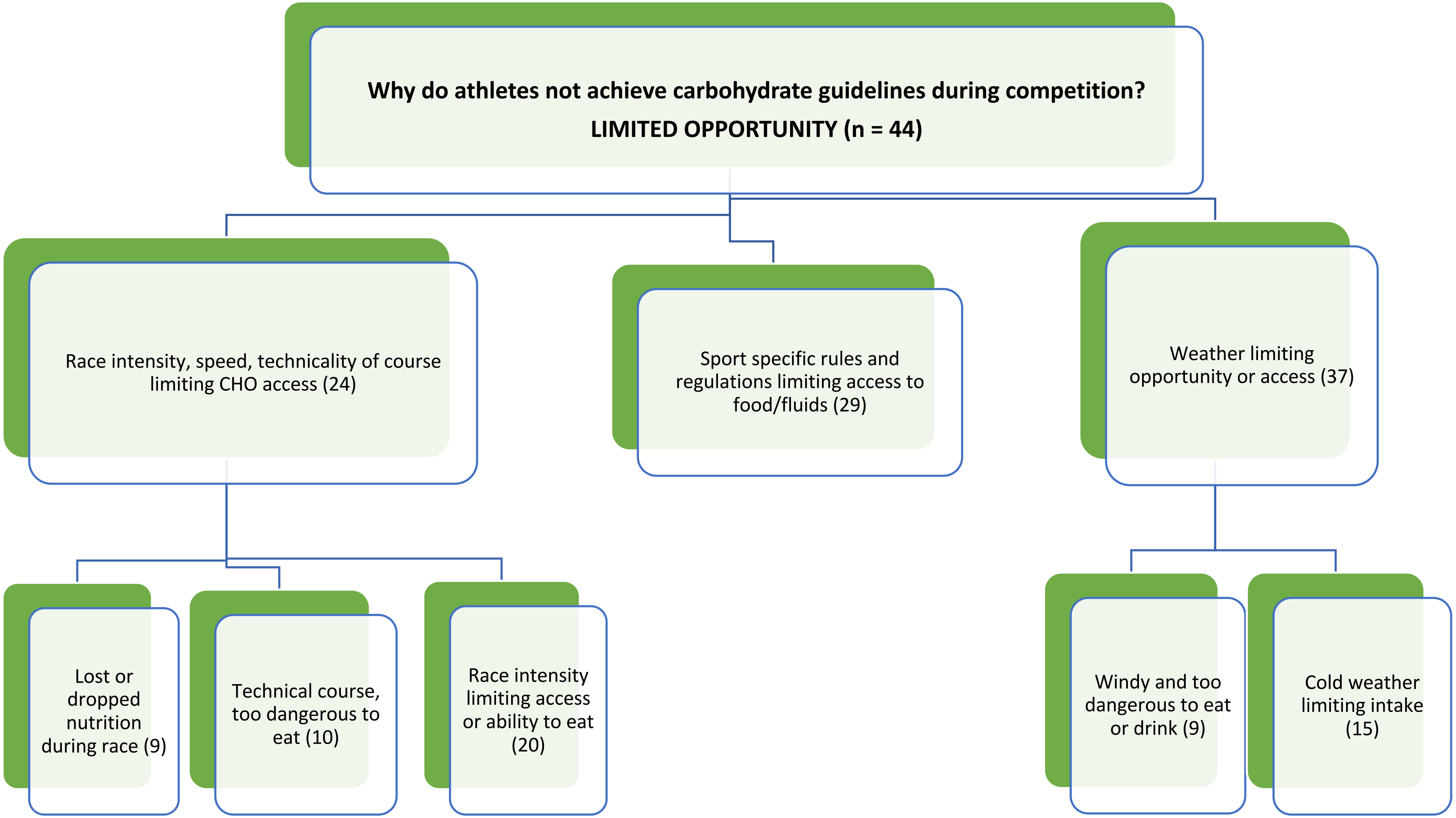


Figure 14. Endurance athletes reported limited opportunity to meet carbohydrate guidelines during real-world competition.

No association was observed between knowledge of CHO guidelines and practice during real-world competition. Reflexive thematic analysis using the COM-B model of behaviour change to explain this lack of association identified that 44 endurance athletes experienced factors within competition that limited the CHO intake that they planned to consume.

6.5.1 Factors influencing carbohydrate loading intake of endurance athletes 24 h before competition

Regarding CHO loading intakes observed in athletes that were not in alignment with guidelines (**Chapter 5**), three prominent themes were developed illustrating how athletes lacked the *capability* (knowledge and skills) to CHO load appropriately (**Figure 12**) and were not motivated to engage in CHO loading due to personal beliefs and fears **(Figure 13**).

Firstly, endurance athletes within this cohort were not reportedly capable of CHO loading due to low theoretical knowledge of current CHO guidelines (**Figure 12**). Assessment of knowledge through the CEAC-Q in the previous study identified only a third of athletes knew that CHO loading intake should be 9 - 12 g•kg^{-1} (**Chapter 5, Table 13 Q8**; n = 18, 36%). Indeed, during interviews only 3 athletes were able to express, without prompt, exactly how much CHO they were aiming to consume the day before competition in either absolute amounts or grams per kilogram body weight (**Appendix 6**).

Secondly, athletes described challenges translating knowledge into practice due to incorrect knowledge of CHO loading practices and conflicting nutrition information and advice. As evidenced in **Table 15**, many athletes lacked knowledge and skills to apply CHO loading practices that would achieve 9 - 12 g•kg^{-1} CHO, with athletes reporting to eat an extra piece of bread (n = 10) or an extra serving of CHO at the dinner meal the night before competition (n = 6) when they practiced CHO loading. Conflicting and misleading nutrition information about CHO loading practices resulted in athletes expressing low confidence in their ability to apply their knowledge to practice. Thirdly, it was apparent from the data that many athletes (n = 43) possessed specific beliefs regarding the need or value of CHO loading upon performance and fears that it would lead to negative consequences such as gaining weight (**Figure 13**). These beliefs and fears prevented many athletes from intentionally incorporating CHO loading as part of their competition nutrition strategy (**Table 16**).

Table 15. Athletes report low capability, knowledge and skills to meet carbohydrate loading guidelines

CAPABILITY TO CARBOHYDRATE LOAD PRIOR TO COMPETITION (n = 42)		
Quote	**Sub theme**	**General theme**
"I don't necessarily know like the grams per, like, grams per kilogram and specific amounts and stuff, but I know roughly what I should be consuming and how much of it." **Athlete 43CAM** *"It's more that I don't just don't really know how much I need to eat, like how much carbs and like what the best meals to do to get that?"* **Athlete 10CAF** *"I've never really believed in any science that there's been any additional value [to CHO loading]. Because of the length of time you'd need to deplete for. So I just kind of keep everything in steady state."* **Athlete 31TAF**	(-) Don't know CHO loading guidelines (21) (-) Low knowledge of CHO content in meals (5). (-) Incorrect knowledge of CHO loading physiology and loading protocols (15)	(-) Low knowledge of CHO loading guidelines (34)
"I think consciously about having more carb meals especially the night before. But yeah, I don't measure any carbohydrate levels or try to achieve a certain goal for the day other than just eat a little bit more than I normally would is kind of what I go with." **Athlete 13TPF** *"Maybe a piece of bread or sweet potato or something else that I include with the food [to carbohydrate load]."* **Athlete 5TPF**	(-) CHO loading means eating more CHO at dinner (10) (-) An extra piece of bread, rice or pasta is CHO loading (6)	(-) Incorrect CHO loading knowledge being translated into practice (13)
"I think that it's more the application for me. I think I've got the knowledge there [of CHO loading] it's just like where do you have it and like what sorts of things I suppose." **Athlete 3TAM** *"I'm not very good, I should probably get better. I'm not very good at calculating how much carb was in like a meal so even though my coach will say "like try and get this much amount of carbohydrate in", I still.. terrible at calculating what's in each meal so have no idea if I hit it or not."* **Athlete 46TPF** *"No, I haven't because frankly, when you read anything like that, I just find it confusing and there's so much different information about how much [CHO] you should have per gram and then weighing it out and all that sort of stuff. I prefer someone to just tell me but give me the reasons and justification around it."* **Athlete 26TPF**	(-) Low confidence in ability to apply CHO loading recommendations into practice (15) (-) Low confidence that intake meets CHO loading targets or not (2) (-) Conflicting nutrition information on CHO loading practice and benefit (5)	(-) Low confidence in ability to translate knowledge to practice when CHO loading (19)

Each factor categorised as having a positive (+), negative (-) or neutral (~) impact on carbohydrate loading intake 24 h prior to competition according to the COM-B and TDF Framework

Table 16. Athletes report low motivation to practice carbohydrate loading 24 h prior to competition

REFLECTIVE MOTIVATION TO CHO LOAD PRIOR TO COMPETITION (n = 43)		
"I've never been one to like I wouldn't probably fancy having a pizza the night before. Like I feel, like happy to eat sort of those starchy white carbs but I prefer to still feel somewhat healthy you know." **Athlete 11TPF**	(-) CHO loading is unhealthy (6)	(-) Personal beliefs that influence athletes to actively limit CHO loading intake the day before competition (43)
"*Yeah, I think a lot of it [CHO loading] is just through doing less training. Anyway, I think that probably helps build the stores [of glycogen] up.*" **Athlete 42TAF**	(-) Tapering and less training means CHO loading is unnecessary (n=8)	
"I've heard so many different things on it [CHO loading]*, obviously I think traditionally it was "you must eat all the carbs in the world before you do a marathon'. But I think that… I've read stuff that it doesn't really make that much difference* [to performance] *so I think that's why I'm I haven't really focused on it."* **Athlete 49RAF**	(-) CHO loading isn't scientifically proven or necessary to improve performance (11)	
"*No. It is better not to really do it* [CHO Load]*. Now just eat like normal, train a little bit less and then you're good."* **Athlete 24TPF**	(-) CHO loading is unnecessary (18)	
"I don't eat carbs; I don't eat pasta and potatoes and rice like heavily normally.. I've tried to the day before the race.. I almost feeling like I'm being really naughty... I don't eat that sort of food normally." **Athlete 48TPF**	(-) Fear of eating CHO foods (5)	(-) Personal fears that influence athletes to actively limit CHO loading intake the day before competition (35)
"I'm always a little scared to change things like that without a good reason to do it. And that's probably why my race day my race nutrition, or in the days leading up probably isn't as good as it should because I think I do need, I probably need to increase something. And I'm so afraid of reacting adversely to the change [by increasing CHO] that I'm like, "Well, at least I know that this is going to get me this result". **Athlete 25TPF**	(-) Fear to change usual CHO content of the diet (n=17)	
"I think during the carb load, definitely feel tired, I felt, tired and heavy, lethargic that sort of stuff. Also yeah just my stomach just felt a bit dodgy it just felt very full all the time and didn't feel like you'd be able to go for a run without need to go to the toilet to be honest." **Athlete 18RAM**	(-) Fear bloating and unwanted GI symptoms (n=17)	
"I also have that like, "Oh I'm gonna feel fat", I don't want to feel different than what I normally do [when CHO loading]." **Athlete 25TPF**	(-) Fear of gaining weight during race (20)	

Each factor categorised as having a negative (-) impact on carbohydrate loading intake 24 h prior to competition according to the COM-B and TDF Framework

6.5.2 Factors influencing carbohydrate intake endurance athletes consume during competition

Overall, as previously captured by the CEAC-Q, most athletes (n = 32) within this study knew and understood current guidelines for CHO during competition and were able to identify they should consume 60 - 90 g•h^{-1} CHO during competition lasting >2.5 h (Chapter 5, **Table 13** Q18c; 64%). Furthermore, during interview 31 athletes were able to express, without prompt, exactly how much CHO they aimed to consume during competition in either grams of CHO or calories or number of gels per hour (**Table 17**). Athletes appeared highly motivated to consume CHO during competition, most recognising the negative impact of performance that occurred when they failed to do so (**Appendix 6**). However, despite possessing good knowledge of CHO guidelines and skills applying this knowledge to practice, almost all athletes (n = 44) experienced situations during competition that limited their opportunity to consume planned CHO, leading to intakes below current guidelines (**Figure 4**). In particular they described uncontrollable factors relating to weather, sport specific rules governing access to nutrition and race conditions on the day negatively influencing CHO consumption during competition, as summarised in **Table 18**.

Table 17. Knowledge of carbohydrate intake to consume during competition (per hour) as expressed without prompt during semi-structured interviews (n = 31)

Carbohydrate aim:	Athlete quote
Aim for 40 - 60g•h^{-1} (n = 4)	*I got off like about 40 to 60 grams an hour."* **Athlete 2CAM**
Aim for 60 - 90g•h^{-1} (n = 8)	*"you can have 60 grams of carbs per hour but if you have a dual source of carbs, you can get it up to 90"* **Athlete 4CAM**
Aim to consume 90-120 g•h^{-1} (n = 2)	*"between 90 and 100 grams of carbohydrates."* **Athlete 20TPF**
Aim to consume 200 - 350kcal per hour (n = 6)	*"for halves [triathlon half Ironman®] like 200 to 250 calories per hour. So [for Ironman®] my coach and I decided to bump it up to 300kcal."* **Athlete 5TPF**
Aim for 1 g•kg•h^{-1} (n = 1)	*aim for 1g of carbohydrate per kg of body weight per hour or something like that*" **Athlete 17CAM**
Aim for 2 - 4 gels per hour (n = 10)	*"on the run you want to be trying to take sort of maybe like three to four gels an hour. I think I usually end up taking two to three depending on the race and how I'm feeling"* **Athlete 42TAF**
Unsure how much CHO to consume per hour during competition (n = 15)	*"I don't necessarily know like the grams per, like, grams per kilogram and specific amounts and stuff, but I know roughly what I should be consuming and how much of it."* **Athlete 43CAM**

Table 18. Athletes report limited opportunity to consume planned carbohydrate intake during competition

LIMITED PHYSICAL OPPORTUNITY TO CONSUME CARBOHYDRATE DURING COMPETITION (n = 44)		
Quote	Sub-theme	General theme
"*if you're on a hilly technical descent, so at Worlds, you know, you wouldn't really be able to eat for like, 20,30 minutes, when you've got to have both hands on the steering, on the on the bike*" **13TPF** "*It can get too intense. Like, lots of attacks happening or something like that, that can make it a lot harder to fuel. Yeah, it's like you don't you don't always have an opportunity to say yeah to grab your drink bottle or do something like that. Or maybe you don't have your drink... You actually run out of food or drink, and you could otherwise go back to the convoy and get something but if the race pace is on, you don't really have that opportunity to [eat]*" **38CAF** "*The last lap in worlds I went to grab a bidon And I grabbed it and I put it like I held the top of it in my mouth to like, hold onto it while I swapped the other one out and then it just dropped. Like the lid came off and dropped and it was gone.*" **7CPF**	(-) Technical course too dangerous to eat (10) (-) Race intensity limiting access or ability to eat (20) (-) Nutrition lost or dropped during competition (9)	(-) Race intensity, speed, technicality of course limiting CHO access and intake (24)
"*All those things technicality locations of feed, length of the race. You couldn't just radio and go back to the car. There was rarely a calm moment in the race whereas other races you can often afford to have someone go back to the car and get you the bidons and you're communicating and radio a lot better.*" **7CPF**	(~) Sport rules and regulations limit when and where able to access nutrition (29)	(-) Sport-specific rules governing food access (n=29)
"*it was really difficult to take a hand off the bars because it was just so windy. Even just like reaching for a bottle was really risky at sometimes*" **39CAF** "*I definitely drink a lot less [energy drink] when it's cold. Even though I know that's wrong. You definitely shouldn't drink much less. But.. I think about drinking less, I guess*" **10CAF**	(-) Windy too dangerous to eat or drink (9) (-) Cold weather limiting intake (15)	(-) Weather limiting access or ability to consume CHO during competition (37)

Key factors limiting planned CHO intake during competition categorised as having a negative (-) or neutral (~) impact according to the COM-B and TDF Framework

6.6 Discussion

The primary aim of this study was to explore factors influencing the mismatch observed between knowledge of CHO guidelines and actual intakes of endurance athletes in real-world competition. Reflexive thematic analysis suggests that the mismatch observed between guidelines and actual CHO loading practices of the endurance athletes within this cohort is demonstrated by low knowledge of CHO loading guidelines, low skills and ability to translate that knowledge into practice (**Table 15,** n = 42), and personal beliefs or fears about CHO loading which intentionally limit intake (**Table 16**, n = 43). Conversely, most endurance athletes in this study knew current CHO recommendations to consume per hour, but experienced external factors during competition that limited the opportunity to eat the CHO they planned and aimed to consume during competition (**Table 18,** n = 44).

6.6.1 Endurance athletes have low *capability* (knowledge & skills) and are not *motivated* to carbohydrate load according to current guidelines

6.6.1.1 Low knowledge of CHO loading recommendations - Unintentionally failed to CHO load due to false perception they were eating a high CHO diet (poor knowledge/capability)

For participants in this study, gaps in knowledge of recommended CHO loading practices may partially explain the 'mismatch' seen during competition. While the CEAC-Q results indicate that a third of athletes knew that CHO loading intake should exceed > 9 g•kg^{-1} (**Chapter 5, Table 13 Q8**; n = 18, 36%), these targets were only achieved by only 8 athletes (**Chapter 5, Table 14, Figure 10A,** 16%). Current CHO loading guidelines prescribe intake relevant to body mass, however only 2 athletes were able to articulate and translate this into the amount of CHO they aimed to consume when CHO loading. One of these athletes shared that *"I'd been advised to try and get between sort of 8 and 10, 8 and 10 grams of carbohydrates to each kilo of body weight was what I'd been given as a target… I think my race weight at that point was about 64 kilos, maybe 65 kilos. And each day, I think I was getting about between 550 and 600 grams of carbohydrate."* **Athlete 18RAM.**

Many athletes were uncertain that CHO could benefit their performance and instead would continue with their habitual diet prior to competition (n = 18). Incorrect knowledge of CHO loading protocols and the physiology behind CHO were loading were evident, with some athletes believing that tapering exercise would allow for glycogen stores to be enhanced without increasing CHO intake (n = 8): "*I think a lot of it [CHO loading] is just through doing less training. I think that probably helps build the stores [of glycogen] up.*" **Athlete 42TAF**. In theory, if these athletes consumed adequate CHO in their habitual diet, then this could be plausible. However, mean intakes observed in this study (**Chapter 5, Table 14,** 6.5 ±2.2 g•kg^{-1}) did not meet recommendations and correlate with previous studies demonstrating that athletes fail to consume adequate CHO the day prior to competition (Masson and Lamarche, 2016; McLeman, Ratcliffe and Clifford, 2019).

Athletes who did not practice CHO loading reported how a lot of nutrition information they accessed on the topic of CHO loading was conflicting and as a result they believed it would not impact their performance and failed to incorporate it into their competition nutrition strategy. *"I've heard so many different things on it* [CHO loading], *obviously I think traditionally it was "you must eat all the carbs in the world before you do a marathon'. But I think that it's less so now that actually it doesn't make.. I've read stuff that it doesn't really make that much difference* [to performance] *so I think that's why I'm I haven't really focused on it."* **Athlete 49RAF.** Half of the endurance athletes assessed in my previous study report to use self-directed learning, citing websites, books and podcasts as their primary source of sports nutrition information (**Chapter 4, Table 10**, n = 526, 52%). Nutrition information and advice available online may be misleading, incorrect and partially responsible for why endurance athletes fail to meet recommended CHO targets the day prior to competition.

In addition to low knowledge of CHO loading recommendations and protocols, many athletes had incorrect knowledge and beliefs of the CHO content of foods and the actual amount of food required to adequately CHO load. In particular, some athletes believed that they were carb loading if they ate a 'big dinner', or if they had an additional serving of carbohydrate in meals. *"I made some toast. And that was like my carb loading, that was the extra carbs that I had: two pieces of bread."* **Athlete 25TPF**. From a practical perspective an extra serve of CHO in a meal would likely only add an additional 50-100g of CHO to their daily intake, which would still fail to meet recommended targets.

Of the 8 athletes who achieved minimum CHO loading recommendations of 9 - 12 g•kg^{-1} (**Chapter 5, Table 14, Figure 10A**) all except 2 were professional athletes, and all had been provided with nutrition plans by a sports dietitian or coach providing specific amounts of CHO to consume: *"I'd worked with the nutritionist about how fuel the day before the race and during the race... kind of having these carbohydrate guidelines… usually before any one day race, I'll always try to hit the carb goals… I can't remember. I always have to look at it, but I think it's like 600 grams of carbs the day [before competition to CHO load].* **Athlete 1CPF.** It is interesting to note, that even when external nutritional guidance, athletes were not always able to recall the specific details of what they would aim to consume without specific guidance. As first observed almost 25 years ago by Burke and Read (1987) my findings demonstrate that athletes attempting to CHO load in a free-living situation, without specific instructions, are still limited in their ability to achieve the dietary requirements for CHO loading.

6.6.1.2 Athletes possess low confidence in their ability to apply knowledge or skills of carbohydrate loading into practice

The data overall suggests that most athletes (**Appendix 4,** n = 28) can describe the skills to adapt specific foods the day before competition to reduce fat, fibre, protein and optimise CHO "*I'll just naturally move more towards carbohydrates, a little bit less fibre, a little bit less protein. And definitely I try to limit my fat, my fat intake the day before, and you know, probably the two days out, but just because I start to prioritize those carbohydrates a little bit more."* **Athlete 15TPF.** However, as only 32% (n = 16) met CHO loading targets. they lack knowledge of actual amounts of CHO required to achieve these targets and experience challenges translating knowledge to practice.

Indeed, many athletes (n = 21) reported low confidence in their ability to apply their knowledge of CHO into practice the day before competition. *"I think that it's more the application for me. I think I've got the knowledge there it's just like where do you have it [CHO] and like what sorts of things [to eat] I suppose.* **Athlete 3TAM.** Even when they received a nutrition plan or had explicit CHO targets [e.g. to consume 600g **Athlete 1CPF**], many athletes reported being uncertain about whether they could achieve CHO targets within meals or across the day: *"I'm not very good at calculating how much carb was in like a meal so even though my coach will say "like try and get this much amount of carbohydrate in", I'm still terrible at calculating what's in each meal so have no idea if I hit it or not."* **Athlete 46TPF.** Athletes with low knowledge and skills to accurately calculate CHO in meals need practical advice and solutions to address this. This may include nutrition education regarding food portion sizes or use of nutrition analysis tools such as the MyFitnessPal™ app to help calculate CHO in meals and achieve targets: *"when I first was trying it [CHO loading], a lot times I have to actually track it [CHO] in MyFitnessPal™ or some nutrition app, food tracker, because it's so much food [to consume when CHO loading]"* **Athlete 1CPF.** Using a nutrition tracker to monitor food intake was a tool used by some of the 8 athletes who did achieve CHO loading to help ensure they met CHO targets and may be a suitable behaviour change technique for self monitor intake.

6.6.1.3 Personal beliefs and fears limit endurance athletes' motivation to carbohydrate load prior to competition

An athletes' habitual dietary choices and personal beliefs can be strong drivers influencing their food intake during competition. The desire to maintain an ideal physique may play an important role dictating food choices and CHO intake during competition (Heaney et al., 2011; Thurecht and Pelly, 2019; Thurecht and Pelly, 2020; Bentley et al., 2021). As highlighted in **Table 16,** almost all athletes (n = 43) expressed either a belief or fear regarding CHO that motivated their engagement. In particular, almost half (n = 20) of athletes spoke about fears of gaining weight or being heavy if they CHO loaded or increased CHO intake. This fear was shared by both male and female athletes and is, in itself, not a new finding. Indeed, 52% of amateur cyclists did not intend to CHO load prior to their race because they believed they didn't need it or feared gaining weight (Sparks et al., 2018). Likewise, athletes may deliberately consume fewer CHO during competition due to beliefs of an overall superiority of low CHO diets (McLeman, Ratcliffe and Clifford, 2019). I found that many athletes believed that eating their habitual diet is better than CHO loading, had a habitual diet that usually avoids CHO foods and subsequently feared changing CHO content of the diet as required to achieve CHO loading guidelines: *"I don't eat carbs, I don't eat pasta and potatoes and rice like heavily normally.. I've tried to the day before the race.. I almost feeling like I'm being really naughty... I don't eat that sort of food normally."* **Athlete 48TPF.**

Similarly, the influence of knowledge gaps of CHO loading practices were evident whereby some athletes (n = 11) were of the opinion that CHO loading isn't scientifically proven or necessary to improve endurance performance: *"I've heard so many different things on it [*CHO loading], *obviously I think traditionally it was "you must eat all the carbs in the world before* *you do a marathon'. But I think that… I've read stuff that it doesn't really make that much difference* [to performance] *so I think that's why I'm I haven't really focused on it."* **Athlete 49RAF.** Understanding athletes' knowledge and beliefs on CHO is important because choice or aversion of specific foods during may be dictated by misconceptions or inadequate information (Worme et al., 1990). These beliefs and fears clearly act as strong motivators for an athlete to change their dietary behaviour and explain in part why athletes fail to achieve recommended CHO loading guidelines. Once identified, they can be suitably addressed via targeted nutrition education, interventions and behaviour change techniques (Michie, van Stralen and West, 2011; Michie et al., 2013).

6.6.2 Endurance athletes have good knowledge of carbohydrate guidelines during competition however experience limited *opportunity* to consume it within competition

6.6.2.1 Athletes clearly understand and know CHO guidelines for optimal performance during competition

The majority of athletes within the study cohort possessed good theoretical knowledge and understanding of current guidelines for CHO during competition. As assessed using the CEAC-Q, 32 athletes were able to identify CHO guidelines consume 60 - 90 g•h^{-1} during competition lasting >2.5 h (**Chapter 5, Table 13** Q18c; n = 32, 64%). During interview, 20 athletes were able to express, without prompt, exactly how much CHO they were aiming to consume during competition in either grams of CHO per hour (n = 14) or calories per hour (n = 6) or number of gels per hour (**Table 17**). However, misinformation and knowledge gaps of recommended CHO practices prevails. Indeed, despite current CHO guidelines being expressed in grams per hour, 6 athletes planned their intake during competition in terms of calories, aiming to consume between 200 - 350kcal per hour (equating to 50 - 75g CHO) which could result in CHO intakes below recommendations if they had been advised incorrectly.

Clear differences in the knowledge, beliefs and nutritional practices of less experienced amateur athletes were evident compared to those of experienced professional athletes. Although not captured by the CEAC-Q, less experienced athletes were more inclined to avoid or under consume CHO during competition: "*I don't need anything while running. I don't know. I guess I just don't really, I've never eaten while running, I've never actually tried to eat while* *running."* **Athlete 40TAM** and demonstrated that they did not know current CHO guidelines or practice them in training or competition. Professional athletes however were very clear on how important it was to consume adequate CHO during competition to optimise their performance and prioritised this practice. Often this awareness of the importance of adequate CHO for performance was the result of learning from a previous experience where they had failed to consume CHO and performance had been subsequently compromised (**Appendix 6, Automated Motivation,** n = 25): "*So from that day onwards, I've kind of acknowledged the importance of nutrition in my racing and I think I'm pretty consistent.* **Athlete 13TPF".**

Athletes who planned their CHO intake ahead of their race were more likely to achieve intakes closer to guidelines, compared to those who raced with no nutrition plan. While most athletes planned to consume CHO intake according to time (n = 32), some ate whenever possible (n = 4) or preferred to use distance (n = 3) or feel (n = 4) to dictate intake (**Table 17**). Using external factors to prompt food intake during competition acted as a protective mechanism to minimise low CHO intake during competition. For e.g. *"every 15 minutes.. my computer will beep and that is a tool that I use to keep me on a feeding schedule."* **Athlete 15TPF.** Throughout these interviews, athletes expressed high levels of motivation to consume adequate CHO during competition to optimise their performance and most had the capability, knowledge and skills to do so.

6.6.2.2 During competition athletes are exposed to situations that limit the opportunity to consume adequate carbohydrate and apply this knowledge to practice.

The unique dynamics of a sport and team culture, role within a team and race position including racing in a breakaway, varying intensity, aggressive race tactics may strongly influence access and CHO consumption (Burke, 2001; Ebert et al., 2007; Heikura et al., 2019). There is often little control over some of the circumstances faced during a race which will directly impact the opportunity to eat CHO. In particular, 44 athletes described the manner in which weather, race intensity, speed, course technicality and sport-specific rules limited access to food or fluid during competition. "*I'm looking at time, decent, intensity, weather, so everything really, just like well the intensity and that type of thing or if you know you got a big climb coming up or something yes a technical descent or that type of thing.. I find if I know that I've got a big section coming up where I won't be able to eat and that type of thing I'm making sure that,* *make sure that I fuel myself enough because I know I won't be able to, like I may not be able to get any nutrition in in that period of time.*" **Athlete 21CAF**. Cold weather and extreme wind posed large challenges to consume adequate CHO during competition, despite having adequate bars, gels or drinks planned and available.

While in some circumstances these factors can be accounted for by adapting the concentration of CHO mix in bottles or using gels, certain weather conditions made it too dangerous to access, meaning athletes were unable under-consumed the CHO available to: *"it was really difficult to take a hand off the bars because it was just so windy. Even just like reaching for a bottle [of energy drink] was really risky at sometimes*" **Athlete 39CAF.** The impact of weather in nutritional adherence has previously been demonstrated by triathletes who consumed more CHO (53 vs 41 $g{\bullet}h^{-1}$) in warm than in mild weather races (Cox, Snow and Burke, 2010) and cyclists who consumed greater amounts of solid foods on cooler days than when racing in warmer weather (Ebert et al., 2007). In addition to this, each sport and race has different rules, regulations that govern when an athlete is allowed to access food or nutrition. *"All those things technicality locations of feed, length of the race. You couldn't just radio and go back to the car. There was rarely a calm moment in the race whereas other races you can often afford to have someone go back to the car and get you the bidons."* **Athlete 7CPF.** External provision of food by race organisers or team, support riders or vehicles could influence the opportunity to consume adequate CHO during competition (Burke, 2001; Ebert et al., 2007). These factors meant that athletes wishing to consume more CHO during competition, often did not have the opportunity to.

Similarly, losing nutrition during race played a big role in low CHO consumption, whether it's from dropped bars or gels or bottles of energy drink that are ejected from their bottle cages mid ride. Nine athletes in this study **(Table 18)** lost nutrition within their race and described the impact this had on their CHO intake: *"The last lap in worlds I went to grab a bidon And I grabbed it and I put it like I held the top of it in my mouth to like, hold onto it while I swapped the other one out and then it just dropped. Like the lid came off and dropped and it was gone."* **Athlete 7CPF.** Some athletes (n = 15) spoke about how consciously aware they are of the challenges that losing nutrition can play on their performance during competition and account for these by carrying extra food, drinks or gels. *"I carry more than I need. Because, you know, sometimes it gets sticky, adrenaline's high, you can drop a [CLIF energy] blok or two... I would rather have more, than you know need and not have it."* **Athlete 15TPF**. While these athletes felt more confident having additional nutrition available 'just in case' others were averse to carrying additional weight on their bike or person during competition.

In some situations, these race specific factors that had the potential to limit CHO intake including weather, course technicality or intensity could be accounted for ahead of time by eating proactively or altering the type of food, fluids, solids or gels consumed. *"I did some races where I lost my energy and you have to have like a plan B for what if this happens, and if that happens and yeah so there's definitely a bigger focus. There's always, yeah, something always like happens differently than you thought so yeah, I think for us for energy and for like a lot of different factors. You have to have different plans or at least be aware that they could change and then you just need to adjust along the way."* **Athlete 22RAF**. This captures the process athletes described of the planning race nutrition while being adaptable in the moment to account for these unexpected circumstances.

6.6.3 Limitations

The primary goal for the study interviews were to discuss the race in which the athlete had recorded food intake, however athletes would frequently reflect on previous races, what they had learnt, done wrong and subsequently changed. The current analysis focused primarily on interpretation of what athletes explicitly said, however the conversation will be influenced by the relationship and rapport between interviewer and interviewees, literacy, personality, motives and even mood on the day (Randall and Phoenix, 2009). To account for any bias or change in dietary practice, athletes were asked whether recording their food intake changed their practice at all "*It didn't change. It made me think about it more, but it didn't make it change it because I was, I'm always a little scared to change things like that without a good reason to do it. And that's why my race day nutrition, the days leading up probably isn't as good as it should be because I probably need to increase something. And I am so afraid of reacting adversely to the change.."* **Athlete 25TPF.**

As a researching practitioner, I was consciously aware of my capacity to lead and direct their thinking (Tollefson et al., 2014). It was a difficult process to step back and allow interviewees to follow their thoughts while identifying the next cue to enhance data outcome (Tollefson et al., 2014). My role as a sports dietitian and clients I work with (and are paid by) typically expect that I will provide the answers or solutions to the challenges they face during competition. Indeed, the financial success of a business is hinged upon clients achieving results rapidly as a result of whatever advice, education or interventions I provide. While I would instantly identify an answer to their nutritional problems being described, what was interesting to note and observe, was that by remaining silent and allowing the athletes to reflect within these interviews, they would often come across a solution by their own account. By pausing and allowing them to reflect on their nutritional challenges, many began to recognise where they could have improved their CHO intake without my direct input. Incorporating motivational interviewing skills like these in dietetic practice have been demonstrated to support positive dietary behaviour changes (Brug et al., 2007; Britt and Blampied, 2015).

With the aim to identify and make sense of patterns of meetings across a data set, qualitative research using thematic analysis poses a known risk of subjectivity whereby another researcher could reach a different conclusion from the data (Braun and Clarke, 2020). The unique experience, knowledge and factors which influence CHO intake of athletes will impact the generalizability of research findings (Smith, 2017). As detailed in the methodology, care was taken to ensure research findings expressed the experience of participants and reflect upon how the CEAC-Q might have the potential to impact practice (Smith, 2017). Upon reflection, 50 study participant numbers may exceed those necessary for qualitative research and influenced the high number of codes generated during inductive thematic analysis (**Appendix 3 - 6**) (Braun and Clarke, 2019b; Braun and Clarke, 2019a). Field notes suggest that data saturation was likely achieved after approximately 10 interviews, however, as interviews were not transcribed until data was collected and complete from all participants from Study 3 this is retrospective (Braun and Clarke, 2019b).

6.6.4 Ability for CEAC-Q, dietary records and interviewing to identify how *capability, opportunity and motivation* influences dietary practice of endurance athletes within competition.

A key role of a practicing sports dietitian is to translate complex information (including CHO guidelines), educate and support athletes to make nutritional changes to their CHO intake during competition for improved performance outcomes (Bartlett and Drust, 2020). The ability to translate sports nutrition guidelines into practical advice that can be applied by an athlete during competition is thus an essential skill. The CEAC-Q and subsequent qualitative research has identified knowledge gaps, beliefs, fears and misconceptions regarding CHO loading, that require education, training and suitable behaviour change interventions to address this mismatch. While overall knowledge of recommended CHO during competition is good, almost all athletes in this study describe challenges *translating* this in practice due to external factors within competition limiting the opportunity to consume CHO that they knew and planned to eat.

During interviews exploring factors influencing food intake within competition, athletes were able to reflect upon their race nutrition practices, with 17 verbalising that if they had been better prepared, thought ahead of time and made a nutrition plan, they would be able to eat better the day before competition. *"Because it's pre-race you've got so I think I'm too distracted and I'm not planned enough because of everything else that's going on with getting to the race, the setting up for the race with registering. I think I fail in my, my plan to be prepared because you're not at home, you don't have access to the foods that you want all the time, and you don't sometimes have enough time. I think I should be a little bit more prepared and planned and know that, getting more carbs into me, the two days or so beforehand, it's going to be far more beneficial for me."* **Athlete 16TPF**. This representative commentary suggests athletes may place inadequate attention to their pre-race nutrition strategies and have knowledge gaps that require further education and training.

In this study, endurance athletes were found to lack the *capability* and *motivation* to CHO load the day before competition due to low knowledge, skills to apply this knowledge, as well as beliefs and fears that CHO loading will not optimise performance. Conversely, despite knowing how much CHO to consume during competition, athletes in this study reported being frequently exposed to a range of external factors that limited the opportunity for them to consume planned CHO intake in real-world competition. Sports dietitians can systematically use the CEAC-Q, dietary records and motivational interviewing skills in nutritional counselling sessions to help identify gaps in knowledge, beliefs and external factors that may influence why athletes fail to achieve recommended CHO within competition. These assessment tools can be used to guide dietary education interventions and behaviour change techniques that enhance the *capability, opportunity* and *motivation* for athletes to optimise CHO intake.

6.7 Reflective pause (Study 4)

As a sports dietitian who is usually paid to give nutrition advice, when interviewing athletes for this study I would frequently find myself wanting to provide my professional input and advice to help the challenges the athletes in my study provided. I learned to bite my tongue on many occasions, to listen more and wait. By not providing advice, I observed that athletes were more inclined to reflect on their practice and identify where they could improve, which may motivate them to make changes. Engaging in these interviews made me question how rapidly I provide the 'answer' to an athlete within my practice and business where time is money, and whether I allow them ample time to reflect on their practice. As a sports dietitian providing nutritional counselling, through motivational interviewing asking the right questions, it is possible to motivate athletes to become aware of the gaps in their knowledge and practice and support them to identify solutions to optimise CHO intake for future competition. Through this research I have discovered how valuable a skill motivational interviewing is within my practice as a sports dietitian to identify any limiting factors regarding capability, opportunity and motivation to better empower my athletes to engage in desirable behaviour change. These skills will require further development and ongoing fine-tuning in my practice.

The process of thematic analysis was extremely challenging, taking almost a year to fully understand my data, what it meant and how to use it. I used the first 6 weeks of the strict COVID-19 lockdown in Spain to transcribe my interviews which fully immersed me in the dataset and enhanced my self-management skills: *"Since lockdown I have become more thorough and disciplined with my time management which is helping me get more done – but also to prioritise time off for play and relaxation and to enjoy life in the present not just look forward to one day in the future. Life is too short! (4.6.20).* Transcribing interviews myself was a valuable process to begin incorporating the CEAC-Q within my business "*it's becoming more apparent to me that I need to create good quality resources that I can share with my athletes, that are specific to each section of the CEAC-Q, but also the practical tips and advice based on the feedback I send to each athlete. E.g. if optimal recovery is 1.2 g.kg CHO, what does that look like in practical amounts with 4 or 5 examples of how that can be achieved with food (31.3.20)".* Reviewing these transcripts and reflections have identified many educational strategies to incorporate within my practice. It is plausible that sharing practical tips, education and advice to support athletes to overcome these challenges and barriers may help close the gap between recommended and actual CHO intakes observed in the literature and practice.

Chapter 7

Synthesis of Findings

7.1 Synthesis orientation

The purpose of the following chapter is to assimilate and articulate the research and professional outcomes achieved as a consequence of this Professional Doctorate. The key results are described and critiqued followed by a meta-reflection which aims to capture elements of the professional development journey. Finally, the thesis closes by outlining recommendations for future research and professional development.

7.2 Achievement of aims and objectives

As observed in the literature and in my professional practice as a sports dietitian, many endurance athletes fail to achieve current CHO guidelines for optimal performance within real-world competition. The overall aim of this Professional Doctorate thesis was to investigate whether athletes fail to consume recommended CHO intakes within competition because they were *unaware* of the current CHO guidelines, have difficulties with *translating* knowledge into practice, have *personal beliefs* or are exposed to *external factors* which influence their intake during competition. This aim was aimed to be achieved by completion of four consecutive studies with the following objectives. The impact of these objectives was anticipated to guide targeted nutrition education, interventions and strategies to optimise dietary intake of endurance athletes in competitive settings in alignment with CHO guidelines.

7.2.2 Achievement of research aims and objectives

Objective 1: Develop a reliable and valid, time-efficient tool to objectively assess endurance athlete's knowledge of CHO requirements for competition (Study 1, Chapter 3 and Study 2, Chapter 4).

To be able to objectively quantify knowledge, Study 1 developed the Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q) based upon contemporary CHO guidelines and validated it with three distinct groups. A significant difference between total and sub-section CEAC-Q scores was evident between the general population (17 ±20%); endurance athletes (46 ±19%); and sports dietitians/nutritionists (76 ±10%, $p < 0.001$). Study 2 subsequently assessed current knowledge levels within a large international cohort of endurance athletes (n = 1016) with mean total and subsection CEAC-Q scores of 50 ±20% and 10 ±5 respectively. Endurance athletes were found to lack knowledge of current CHO guidelines, with just 28% of athletes able to identify 9 - 12 g•kg^{-1} for CHO loading, 48% identifying to consume 60 - 90 g•h^{-1} during competition lasting > 2.5 hours and 29% identifying 1 – 1.2 g•kg^{-1} post exercise for rapid recovery. The CEAC-Q rapidly identified many CHO knowledge gaps of endurance athletes that could be targeted via specific nutrition education.

Objective 2: Quantify the relationship between endurance athlete's knowledge of CHO requirements and dietary CHO intake before and during competition (Study 3, Chapter 5).

Study 3 measured the practical application of using the CEAC-Q in the field and evaluated the relationship between knowledge and dietary intake within 50 amateur and elite endurance athletes competing in real-world competition. Mean CHO loading intakes of athletes (6.5 ±2.2 g•kg^{-1}) was below guidelines, with just 8 athletes (16%) achieving recommended intakes for CHO loading in the 24 h prior to competition (9 - 12 g•kg^{-1}). CHO pre-competition meal guidelines (1 - 4 g•kg^{-1}) were achieved by 80% of athletes (n = 40) with mean intakes of 1.5 ±0.6 g•kg^{-1} and only 32% (n = 16) of athletes met guidelines of 60 - 90 g•h^{-1} during competition with mean intakes of 52 ±2 g•h^{-1}. No association was evident between knowledge of CHO guidelines and dietary intake for CHO loading, the pre-competition meal or during competition.

Objective 3: Qualitatively assess the reasons underpinning endurance athlete's dietary CHO choices for competition through the lens of behaviour change models (Study 4, Chapter 6).

Study 4 subsequently conducted semi-structured interviews to explore factors explaining the lack of association between knowledge of CHO loading and during competition guidelines and CHO intake with the same cohort of athletes from Study 3 (n = 50). Reflexive thematic analysis applying the COM-B model of behaviour change as a theoretical framework observed that athletes lack the *capability* to CHO load 24 h prior to competition due to low knowledge of CHO guidelines, and *motivation* to CHO load due to personal beliefs or fears that CHO loading is unnecessary and will not optimise performance. Conversely, despite knowing CHO guidelines during competition, athletes were frequently exposed to a range of external factors during competition [weather, race conditions, rules regulations] that limited the *opportunity* for them to apply their knowledge into practice and consume planned CHO intake.

7.2.2 Achievement of professional development aims and objectives

The professional development aims of the Professional Doctorate process were to enhance my personal effectiveness, engagement, influence and impact as a sports dietitian. These aims were achieved by the investigations conducted in **Chapters 3, 4, 5 and 6** and professional development outlined throughout the reflective pauses. Further detail around specific outcomes that fulfilled these aims are outlined in the objectives below.

Objective 1: To enhance my research skills and experience as an applied researching sports dietitian.

Achievement of objective 1 was demonstrated in **Chapters 3, 4, 5 and 6** through a mixed-methods approach collecting both quantitative and qualitative data that could be used within my practice educating and providing nutrition interventions to athletes. With each of the investigations outlined, results were collected, analysed, presented and disseminated in a variety of methods. Skills analysing nutritional data based on photographs (Remote Food Photography Method), using statistical packages (SPSS), creating visual graphs (Graphpad Prism) and conducting qualitative semi-structured interviews were all developed. In addition, my capacity to engage athletes and potential clients using the findings of my research has enhanced an important skillset as an applied practitioner.

Objective 2: Further develop my time management skills, responsiveness to change and work-life balance as a self-employed sports dietitian.

Achievement of objective 2 was demonstrated in the reflective pause of **Chapter 6**. As a self-employed dietitian, COVID-19 had a strong negative impact on my business from a financial perspective due to cancelled events and clients which subsequently delayed the planned timeline to complete my Professional Doctorate. Engaging with a business coach to restructure my business and incorporate the CEAC-Q research findings, weekly accountability meetings with the supervisory team and peers, establishing clear structure to my day in alignment with goals enhance my time management skills, responsiveness to change and supported better work-life balance whereby I no longer worked 7 days a week and took weekends off.

Objective 3: To develop communication and dissemination skills both with my professional peers and athletes.

Achievement of objective 3 was demonstrated throughout all chapters of the thesis providing evidence of scientific writing, with Study 1 (**Chapter 3**) currently under revision for publication. Scientific writing skills improved greatly following ongoing feedback and constructive critique from my supervisors. The findings of the research from Study 1 were presented live to the scientific community at the International Sports and Exercise Nutrition Conference (ISENC) in Newcastle December 2019, as well as presented to the online sports nutrition community COVID19 conference. The CEAC-Q has subsequently been used in observational research conducted by the Australian Catholic University in 65 endurance athletes racing on Zwift, observing comparable CEAC-Q total 51 ±22% and subsection scores of 10 ±6 (personal communication). Blog articles on my website (www.gemmasampson.com), nutrition podcasts and social media content on Instagram @gemmasampsonnutrition regularly share sports nutrition information that aim to reach and educate a broad audience of endurance athletes.

Objective 4: Use these research findings within my personal practice as a sports dietitian to more effectively educate athletes and deliver sports interventions that support changes in dietary behaviour.

Achievement of objective 4 was demonstrated in the reflective pauses of Chapter 4, 5 and 6. As a result of the findings from this Professional Doctorate research, the CEAC-Q has become an integral part of my business and professional practice, used as an onboarding tool to assess baseline knowledge of new clients prior to any nutrition counselling or interventions being provided. This has developed a systematic process where I as a sports dietitian can use the CEAC-Q, dietary records and nutritional counselling skills (i.e. motivational interviewing) within my business and practice to identify gaps in knowledge of CHO guidelines, beliefs and external factors that may influence why athletes fail to achieve recommended CHO within competition. Following administration of the CEAC-Q in Study 1 (**Chapter 3**), a small significant learning effect was observed in endurance athletes, demonstrating a potential use of the CEAC-Q to identify knowledge gaps prior to targeted nutrition education and increase the capability and motivation of athletes to change behaviour. Collectively, these assessment tools can be used to guide appropriate education and dietary interventions using the most appropriate behaviour change techniques to enhance the capability, opportunity and motivation for athletes to optimise CHO intake within competition. How this is currently incorporated into my professional practice and will continue to be developed and refined beyond completion of the Professional Doctorate is further discussed in 7.4.2.

7.3 General discussion of findings

Current CHO guidelines are based upon a wealth of literature demonstrating performance benefits when endurance athletes compete with optimal CHO availability (Burke et al., 2001; Jeukendrup, 2004; Burke et al., 2011; Kerksick et al., 2017; Impey et al., 2018). Despite this strong scientific evidence and sports nutrition guidelines recommending CHO intakes to enhance endurance sports performance, as highlighted within the Literature review (**Chapter 2**, **Tables 1 and 3**) a clear mismatch exists between current guidelines and practice amongst endurance athletes (Burke et al., 2001; Spronk et al., 2015; Masson and Lamarche, 2016; Heikura et al., 2017b; McLeman, Ratcliffe and Clifford, 2019). Identifying whether athletes fail to achieve CHO recommendations within competition because they are *unaware* of the current CHO guidelines, have difficulties with *translating* knowledge into practice, have *personal beliefs* or are exposed to *external factors* which influence their intake during competition is key to provide appropriate education and interventions that drive dietary changes.

7.3.1 What do endurance athletes know about carbohydrate for performance?

As identified in the Literature Review (**Chapter 2**), no existing nutrition knowledge questionnaires exclusively assessed knowledge of CHO guidelines for endurance athletes. Subsequently in Study 1 (**Chapter 3**) we developed and validated the Carbohydrates for Endurance Athletes in Competition Questionnaire (CEAC-Q) with mean total and subsection scores of 46 ±19%; 9 ± 5% obtained in 145 endurance athletes. These findings were comparable with those collected in a large cohort (n = 1016) of athletes in Study 2 (50 ±20%; 10 ±5%, respectively) as well as Study 3 (55 ±15%; 11 ±5). Previous studies had observed that just 4% of amateur runners could correctly identify the amount of CHO required for loading (McLeman, Ratcliffe and Clifford, 2019) and only 25% of triathletes correctly identifying the recommended amount of CHO to consume post exercise for optimal recovery (Doering et al., 2016). Similar findings were observed in Study 2 whereby 28% of athletes identified 9 - 12 g•kg^{-1} for CHO loading, and 48% identified 60 - 90 g•h^{-1} during competition lasting >2.5 hours and 29% identified 1 – 1.2 g•kg^{-1} post exercise for rapid recovery (**Chapter 4, Table 11**). I also identified that years of competitive experience, competitive level and a sports nutritionist influence are positively related to CEAC-Q scores. Importantly the CEAC-Q allowed to identify areas of high, medium and low knowledge of endurance athletes in different key knowledge areas of CHO for competition that may require targeted education.

7.3.2 How does knowledge of carbohydrate guidelines translate to practice?

On the basis of findings from Study 1 (**Chapter 3**) and 2 (**Chapter 4**) we aimed to explore how this knowledge of CHO guidelines were associated with dietary practice within real world competitions. Study 3 (**Chapter 5**) observed that while only 36% of athletes could identify **9 - 12 g•kg^{-1}** when CHO loading, 38% knew to consume **1 - 4 g•kg^{-1}** in the pre-competition meal and 64% identified to consume **60 – 90 g•h^{-1}** during competition, this knowledge did not translate into practice. Just 16% and 32% of athletes achieved CHO guidelines for CHO loading 24 h prior and during competition lasting >2.5h respectively, while 80% achieved the pre-competition CHO guidelines target (**Chapter 5, Table 14**). No was association evident between total CEAC-Q scores, subsection scores or identified guidelines and dietary intakes consumed by endurance athletes within real-world competition (**Chapter 5**, **Table 13**). As knowing the CHO guidelines did not consistently translate to practice for study participants, our findings indicated that behaviour change approaches used by sports dietitians may need to focus on factors beyond improving knowledge of CHO guidelines in isolation.

7.3.3 What factors influence the mismatch observed between knowledge and practice?

To better understand the lack of association between knowledge and practice, Study 4 (**Chapter 6**) qualitative interviews explored factors that explain the observed mismatch between knowledge of CHO guidelines and actual CHO intakes of endurance athletes during real-world competition. These factors were categorised according to the COM-B model of behaviour change establishing different factors influenced the lack of association between knowledge and practice of CHO loading and during competition. Athletes did not achieve CHO loading targets due to low knowledge of and skills to apply CHO loading guidelines in practice (*capability*) as well as poor *motivation* to CHO load due beliefs and fears that it is unnecessary and will not optimise performance. Conversely, despite a good level of nutrition knowledge of CHO guidelines during competition, athletes in this study reported being frequently exposed to a range of external factors during competition that hinder the *opportunity* for them to apply this knowledge and consume planned CHO intake.

7.3.4 Practical application of the CEAC-Q questionnaire

A key role of a practicing sports dietitian is to translate complex information including CHO guidelines, educate and support athletes to make nutritional changes to their CHO intake during competition for improved performance outcomes (Bartlett and Drust, 2020). Practically, the CEAC-Q has been shown of use as a baseline marker of knowledge levels to identify areas in which endurance athletes require nutritional guidance and these resources are best delivered to support change in practice. As knowledge alone does not translate into practice, nutrition education, interventions and advice with the aim to optimise CHO intake in competition must account for the factors identified in Study 4 (**Chapter 6**) that challenge intake. Once these key underlying factors have been identified using the COM-B model and Behaviour Change Wheel (BCW), they can be suitably addressed via targeted nutrition education, interventions and behaviour change techniques (Michie, van Stralen and West, 2011; Michie et al., 2013) as demonstrated in **Table 19**. The practical findings of the studies in **Chapters 3-6** and the relevant literature review (**Chapter 2**)**,** have guided the development of a business plan to create and provide tailored sports nutrition education that addresses knowledge gaps identified within the 5 CEAC-Q sub-sections following completion of the Professional Doctorate.

Table 19. Targeting barriers to achieve CHO guidelines within competition: Using the COM-B model and Behaviour Change Wheel to design and deliver nutrition interventions.

Barrier to achieving CHO guidelines	**Intervention function**	**Behaviour Change Techniques**	**Intervention examples to target identified barrier**
Low *capability* to CHO load (Knowledge and skills)	Education Training Restriction Environmental Restructuring Modelling Enablement	Information on consequences Prompt/cues Feedback on behaviour Self-monitoring of behaviour Demonstrate the behaviour Prompts and cues Satiation Goal setting (outcome) Problem solving Distraction	Provide example meal plan containing high CHO diet achieve 9 – 12g.kg Hold educational meetings with athlete to explain the theory behind the nutrition strategies being implemented Use MyFitnessPal™ tracker to record food intake and ensure each meal and daily CHO intake achieves 9-12 g.kg Request the athlete to reduce fibre content the day before competition to minimise bloating Weigh and measure CHO portions in foods consumed Provide examples of what some of the best cyclists in the world are eating the day before to prepare for competition
Low *motivation* to CHO load (Beliefs and fears)	Education Coercion Training Modelling Enablement	Demonstration of the behaviour Self-talk Reduce negative emotions Focus on past success Pros and cons Framing/reframing Self-monitoring of behaviour	Emphasise the negative effects to performance if under consume CHO the day before competition Provide examples of what some of the best cyclists in the world are eating the day before to prepare for competition. Test CHO loading in training, observe temporary changes in weight due to fluid, and normalise within 1-2 days post competition to provide reassurance that 'weight gain' is not fat. Test CHO loading prior to key training session to provide confidence that it is tolerated and can optimise performance of athlete.

Limited *opportunity* to consume CHO during (Weather, race intensity)	Environmental restructuring Enablement Modelling Training Coercion	Prompts/Cues Adding objects to the environment Self-monitoring of behaviour Action planning Behavioural practice	Use Garmin automatic prompts to remind to eat/drink during competition Develop a plan ahead of time of what will eat/drink during competition. Carry extra gel(s) during competition in case lose nutrition or racing longer than planned Use MyFitnessPal™ or TrainingPeaks™ to record CHO intake during competition and compare to guidelines retrospectively to identify where to improve intake Demonstrate what professional athletes consume during competition Practice consuming CHO in training Emphasise negative impact on performance if under-consume CHO during competition Concentrated CHO drink mix or gels instead of solid food in cold/wet weather races

The COM-B model may identify that a key barrier for an athlete to achieve CHO loading guidelines is low *capability* due to low knowledge and skills of CHO loading practices. Suitable interventions to change this behaviour according to the Behaviour Change Wheel may involve education, training or modelling with behaviour techniques providing information, prompts or feedback on behaviour. Suitable interventions to target this identified barrier may include provision of a meal plan to achieve 9-12g.kg CHO, education to explain the theory or use of MyFitnessPal™ to monitor adherence to recommendations (Michie, van Stralen and West, 2011; Michie et al., 2013).

7.3.5 Limitations

Each of the studies within this thesis have produced novel data that has enhanced the body of knowledge and our understanding of knowledge, practice and factors driving the capability, opportunity and motivation of endurance athletes to consume CHO in alignment with current guidelines within competition. Nevertheless, these studies are not without their limitations which are addressed below.

Limitations developing the CEAC-Q (Study 1, Chapter 3)

1. Previous nutrition knowledge validation studies considered a period of 2 - 3 weeks long enough for answers to be forgotten yet short enough to minimize any change in nutrition knowledge. As CEAC-Q knowledge scores increased by 8 ±14 points (equivalent to 2 additional correct questions) between initial and re-test 10 - 14 days later (potentially due to self-learning in between tests), when it relates to athletes' performance this time frame may be too vast.
2. Qualitative data demonstrated how participants chose unsure in one trial and then subsequently selected an answer in the second may explain the increased scores but whether that relates to true increase in knowledge is to be determined.
3. Athletes participating in the study may be personally invested in the topic and more motivated to increase their knowledge, leading to uncontrollable bias. No nutrition education or feedback on scores were provided between tests, however athletes participating in the retest may have been personally invested in the topic and more motivated to increase their knowledge, which could not be controlled.
4. Test conditions should be consistent in repeat trials, however for a self-administered test, no control could be placed over distractions or how much attention a participant takes when completing the CEAC-Q.

Limitations assessing knowledge in athletes using the CEAC-Q (Study 2, Chapter 4)

- Language may pose a barrier to completion and scores obtained by non-English speakers. The CEAC-Q has subsequently been translated into French and Spanish and require further validation in these languages.
- Knowledge gaps amongst a wider population of athletes not interested in sports nutrition may be greater than those recorded.

- In light that 11% of athletes in our study reported that CHO loading has no benefit to performance (Q10), obtaining data regarding beliefs, habitual and competition diet may be relevant to improve the usefulness and context of the questionnaire. However, with increasing number of questions, completion rate decreases.

Limitations assessing the association between knowledge and practice (Study 3, Chapter 5)

- Athletes who participated in this study may be biased and have greater nutrition knowledge than those who did not participate. Although no explicit benefits from participating in the study were provided, athletes who may have greater interest in sports nutrition, desire to improve their performance and perceive a return for their investment of time or energy by receiving nutrition knowledge from a sports dietitian for free.
- Participants could have received more thorough training and familiarising using remote food photography method to reduce dietary recording bias. For example, attendance at a workshop, practicing the method one or two days prior to their event for familiarisation with the method and to improve accuracy, minimise forgotten food photographs.
- A clear limit in the number of participants able to be managed at one time was evident due to need to manually send prompts. Of the 70 participants originally recruited, 20 were lost during study because they didn't receive sufficient prompt reminders or nudges, when racing in different time zones to the lead researcher. If prompts to nudge athletes to send food photos at mealtimes could be automated and account for time zone differences, nutrition data and participant losses may be minimised.
- The retrospective nature of the dietary data collected during competition may not accurately account for all foods and fluids consumed. Recall bias where athletes may have forgotten components of meals, were unable to determine concentration of CHO drinks collected from feed stations, and exact measurements of fluids consumed within bottles could not be measured within this study.

Limitations exploring factors influencing knowledge and practice (Study 4, Chapter 6)

- Semi-structured interviews have potential room for bias and ability to leading the conversation in a certain direction. The lead researcher was conscious that during interviews, questions could be asked in such a way that would get a specific answer and kept field notes throughout this process to minimise this bias.

- Study participant numbers (n = 50) may appear excessive for qualitative research, and data saturation was likely achieved after approximately 10 interviews. However, as interviews were not transcribed until data was collected and complete from all participants from Study 3 this is retrospective.
- Qualitative research using thematic analysis poses a risk of subjectivity whereby another researcher could come to a different conclusion from the data.
- The unique athlete experience, knowledge and factors which influence their CHO intake will impact the generalizability of research findings on an individual level

7.4 Future recommendations

The conclusions in this thesis have provided novel findings in assessing knowledge, practice and factors influencing dietary intakes of endurance athletes during competition. In achieving the aims of the thesis, several other research questions were established which are detailed in relation to each specific chapter of the thesis.

7.4.1 Future research recommendations

Future research arising from Study 2 (Chapter3)

1. Investigate the reliability of the CEAC-Q if test-retest is conducted within 24 hours of initial completion.
2. Investigate the reliability of the CEAC-Q to measure increased knowledge following sports nutrition education or intervention program.

Future research arising from Study 3 (Chapter 4)

1. Design effective and efficient sports nutrition education programmes and interventions targeting evidence-based gaps in sports nutrition knowledge
2. Measure the effectiveness of a tailored sports nutrition education program based upon initial CEAC-Q scores.

Future research arising from Study 3 (Chapter 5) and Study 4 (Chapter 6)

1. Investigate the utility of the CEAC-Q to motivate athletes to change behaviour upon identifying knowledge gaps.
2. Deliver and assess effectiveness of nutrition education programs targeting gaps in knowledge as measured by CEAC-Q and dietary behaviours of athletes within competition.

7.4.2 Future professional development plans

Development of myself as a researcher, practitioner and individual is a continuous process that will continue to evolve beyond the completion of this Professional Doctorate. Throughout the thesis, the key themes for professional development have been captured, particularly focused around professional and career development, self-management, communication and dissemination skills. As highlighted, these skills have all been significantly developed throughout the professional doctorate journey and I intend to continually improve the way I practice, provide nutrition counselling, education, interventions and influence the dietary behaviours of the athletes I work with as follows.

The text and images originally presented here cannot be made freely available via LJMU E-Theses Collection for commercially sensitive reasons.

7.5 Meta-reflection

The professional doctorate journey has been one of the most challenging experiences to date, which has resulted in considerably professional and personal growth. It has been valuable to refine the direction in which I desire my life to take, by clarifying goals and continuing to improve self-management skills, time management and create structure and focus within my business as a sports dietitian. The process has taught me how to better manage high stress levels amidst frequently changing environments without sacrificing my personal life.

Reflecting over the Professional Doctorate journey, one of the most surprising findings has been to realise that my research has shaped the focus and direction of my business. In one sense, although I didn't necessarily expect that to happen, this should not have been such a surprise when considering that indeed the whole point of the Professional Doctorate journey is the interweaving of myself as a researcher, practitioner and individual. Perhaps it took the full journey to discover 'how' this would work, but my initial research development notes indicate that I realised the value of connected my practice, research and business from the start: "*Everything feels much more streamlined now I have the same ONE FOCUS in my business, and in my research – online sports nutrition education. Everything I do, read, write and create is focused around this area – educating cyclists through workshops, webinars and online courses. Then researching and evaluating the effectiveness of this, how good it is at supporting change and getting the results that count (2.5.18).*"

Reviewing over reflective notes highlights how many micro and macro goals that I had achieved throughout this journey as a result of clearly identifying what I wanted to achieve, personally or professionally as well as words of wisdom. "*To be successful in achieving my goals and creating my desired lifestyle I have to get good at saying no to all the people and distractions that would overwise devour me. Successful people know how to say no without feeling guilty (2.6.17).*" Early on I identified things that distract me from my goals, what I needed to do to avoid distraction and make progress by *"protecting time in the day to focus on this [Professional Doctorate] EVERY day. The mornings must be protected, as this is my highest energy time, and most productive (14.3.18)."* Although I didn't properly begin to implement in practice until the COVID-19 lockdown in 2020, creating a daily strict schedule to transcribe the interviews from Study 4. It can be easy to identify what to do, but as is clear from my research knowing WHAT to do doesn't always translate into practice. Not only in the way I provide education and support to my athletes, but I have also learnt personally (through practice, repetition, mistakes and repetition) that small, consistent practices are what get the long-term results. The hard 8-week lockdown I had in Spain created a unique albeit unexpected opportunity to put this into practice, whereby each day I aimed to transcribe a certain number of interviews per day.

Rather than getting overwhelmed at everything that needed to be done, I slowly chipped away at the 50 interviews one-by-one. I recognise that, "*I need to remind myself that I don't have to do everything TODAY. Baby steps, one little thing at a time, to build on the domino effect.*

Don't allow myself to get stuck in the rabbit warren or a downward spiral chasing things that don't matter (15.3.18)". This leads onto the value of accountability within my life personally and professionally to help stay on track with my goals as I do easily get distracted and go down 'interesting but not relevant' pathways that can deter me from my goals. Regular meetings and contact with the supervisory team as well as weekly 'accountability' meetings with a friend and fellow business owner back in Liverpool have helped me to stay focused and achieve my goals within the allocated time. Used together with weekly structured reflective sessions, I now measure the current status of my personal or professional goals in order to adjust, course correct and make changes as necessary. In 2020 when I needed to restructure my business after losing a lot of income due to COVID-19, I employed a business coach for guidance as I identified that I don't have a shortage of ideas, but am challenged when prioritising what to focus on and using the time I have available to the best ability. I have since learnt to focus on the ONE thing that I can do right now that will help me towards my daily, weekly, monthly, annual goals and to focus on that and only that. As such my time management, productivity and output has improved considerably, but require continual refining and reflection to meet deadlines, achieve goals and be responsive to changing environments and work situations.

Over the Professional Doctorate I have learnt to not just rely on others, but to have the confidence in myself and my research. When I was doubting the applicability of the CEAC-Q in Study 1, it was during a team development meeting that I discovered that Prof James Morton had used the questionnaire with all the riders at Team Sky (18.3.19). This provided reassurance that the CEAC-Q was a valuable tool and gave me confidence to start using it in my own practice. Similarly, having presented my initial findings at the ISENC conference in 2019 and again at a virtual online nutrition conference in April 2020, I received positive feedback from other dietitians regarding the usefulness of the questionnaire. I observed that during these moments of doubt, taking action builds confidence "*Nothing happens without action. Whenever I am stuck in overwhelm, anxiety, procrastination of fear, just do something. Anything… If I don't know how to do something, just start writing something down. My brain will begin to figure it out as I go along (17.4.18)."* This has certainly been the case since incorporating the CEAC-Q into my business and using it with clients.

Although my research did not explicitly measure effectiveness as I had originally anticipated, I have learnt through this process that effective interventions are essential to change eating practices of athletes at both elite and amateur level. Who I am as a sports dietitian plays a key role in coaching the athlete towards making positive dietary changes, however there are multiple drivers influencing dietary intake that extend beyond my scope. My job then, is to identify what is driving eating behaviours and provide effective solutions to support sustainable change, which I thoroughly believe my research using the CEAC-Q, analysing food diaries and exploring motivational interviewing have enhanced my capacity to do.

I strongly identified with the challenges associated with applied research as described by (Schon, 1983), where professional practice fluctuates between the "high hard ground" and messy "swampy lowlands", between "rigor or relevance". In a lab or controlled environment, results or conclusions can be clear cut and obvious, whereas real-world results and conclusions are impacted by experience, trial and error, intuition and muddling through (Schon, 1983). The challenge as a researching practitioner is that we must choose to either stay in the high hard ground to solve relatively unimportant problems according to clear-cut standards, or descend into the swampy lowlands of important problems with their non-rigorous inquiry (Schon, 1983). Throughout this Doctorate I have aimed to consistently reflect on knowing-in-action, reflection-in-action and reflection-on-reflection-in-action (Schon, 1983). As so many factors influence the dietary choices and behaviour of athletes (and myself), those swampy lowlands of messy, confusing problems and solutions are where I find myself at the conclusion of the Professional Doctorate. My findings suggest that using the CEAC-Q in practice with endurance athletes individually and at a population level could play a role in motivating athletes to change their dietary behaviour by systematically identifying areas where improvements could be made in CHO knowledge, practice as well as address the unique challenges that may limit intake.

7.6 Professional Doctorate Summary

In summary, the research undertaken in this Professional Doctorate thesis provides novel data and tools to support sports dietitians assessing CHO knowledge and nutritional practices of endurance athletes. Gaps in nutrition knowledge highlighted by the CEAC-Q can be used strategically to guide appropriate nutrition education and interventions when used in conjunction with dietary records and interviewing to identify factors influencing the capability, opportunity and motivation of endurance athletes to change their behaviour.

Having changed roles multiple times within the Professional Doctorate journey, I am now an Advanced Sports Dietitian with a successful, sustainable and systematic private practice working with elite and amateur endurance athletes and have incorporated the CEAC-Q into my business model. Although this was not explicitly measured as part of my research to date, anecdotal evidence from current clients who have completed the CEAC-Q as part of an onboarding procedure suggest that use of the CEAC-Q in practice with endurance athletes could play a role in supporting behaviour change by identifying knowledge areas where changes can be made as well as motivating the athlete to learn themselves. Moving forward beyond the Professional Doctorate I intend to write, develop and create educational resources including blog posts, articles, podcasts and videos that link in strategically to each section of the CEAC-Q to educate athletes about the performance benefits of CHO and how they can translate this knowledge into practice during competition. What is left to discover is the effectiveness of how this in turn influences dietary practice. The process is never complete, and I will continue to engage in reflective practice, refine my practice as a sports dietitian, my knowledge and skills on a daily, monthly and annual basis to assess the efficiency and impact of my research and practice on the knowledge and dietary behaviour of athletes.

References

Alaunyte, I., Perry, J.L. and Aubrey, T. (2015) Nutritional knowledge and eating habits of professional rugby league players: does knowledge translate into practice? *Journal of the International Society of Sports Nutrition*, 12, 18.

Areta, J.L. and Hopkins, W.G. (2018) Skeletal Muscle Glycogen Content at Rest and During Endurance Exercise in Humans: A Meta-Analysis. *Sports Med*, 48 (9), 2091-2102.

Armstrong, L.E., Casa, D.J., Emmanuel, H., Ganio, M.S., Klau, J.F., Lee, E.C., Maresh, C.M., McDermott, B.P., Stearns, R.L., Vingren, J.L., Wingo, J.E., Williamson, K.H. and Yamamoto, L.M. (2012) Nutritional, Physiological, and Perceptual Responses During a Summer Ultraendurance Cycling Event. *The Journal of Strength & Conditioning Research*, 26 (2), 307-318.

Atkins, L. and Michie, S. (2015) Designing interventions to change eating behaviours. *Proc Nutr Soc*, 74 (2), 164-170.

Atkinson, G., Taylor, C.E., Morgan, N., Ormond, L.R. and Wallis, G.A. (2011) Pre-race dietary carbohydrate intake can independently influence sub-elite marathon running performance. *Int J Sports Med*, 32 (8), 611-617.

Bartlett, J.D. and Drust, B. (2020) A framework for effective knowledge translation and performance delivery of Sport Scientists in professional sport. *Eur J Sport Sci*, 1-9 doi: 10.1080/17461391.17462020.11842511. Epub ahead of print. PMID: 33096969.

Batterham, A.M. and George, K.P. (2003) Reliability in evidence-based clinical practice: a primer for allied health professionals. *Physical Therapy in Sport*, 4 (3), 122-128.

Bentley, M.R., Mitchell, N., Sutton, L. and Backhouse, S.H. (2019) Sports nutritionists' perspectives on enablers and barriers to nutritional adherence in high performance sport: A qualitative analysis informed by the COM-B model and theoretical domains framework. *J Sports Sci*, 37 (18), 2075-2085.

Bentley, M.R.N., Mitchell, N. and Backhouse, S.H. (2020) Sports nutrition interventions: A systematic review of behavioural strategies used to promote dietary behaviour change in athletes. *Appetite*, 150, 104645.

Bentley, M.R.N., Patterson, L.B., Mitchell, N. and Backhouse, S.H. (2021) Athlete perspectives on the enablers and barriers to nutritional adherence in high-performance sport. *Psychology of Sport and Exercise*, 52, 101831.

Black, K.E., Skidmore, P.M. and Brown, R.C. (2012) Energy intakes of ultraendurance cyclists during competition, an observational study. *Int J Sport Nutr Exerc Metab*, 22 (1), 19-23.

Blennerhassett, C., McNaughton, L.R., Cronin, L. and Sparks, S.A. (2018) Development and Implementation of a Nutrition Knowledge Questionnaire for Ultra-Endurance Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, 29 (1), 39-45.

Blennerhassett, C., McNaughton, L.R. and Sparks, S.A. (2019) Factors influencing ultra-endurance athletes food choices: an adapted food choice questionnaire. *Res Sports Med*, 27 (2), 257-271.

Bourke, B.E.P., Baker, D.F. and Braakhuis, A.J. (2019) Social Media as a Nutrition Resource for Athletes: A Cross-Sectional Survey. *Int J Sport Nutr Exerc Metab*, 29 (4), 364-370.

Braun, V. and Clarke, V. (2006) Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3 (2), 77-101.

Braun, V. and Clarke, V. (2013) Successful qualitative research: A practical guide for beginners. In: (ed.): London: Sage. pp. 285.

Braun, V. and Clarke, V. (2019a) Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11 (4), 589-597.

Braun, V. and Clarke, V. (2019b) To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales. *Qualitative Research in Sport, Exercise and Health*, 13 (2), 201-216.

Braun, V. and Clarke, V. (2020) One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 1-25 DOI: 10.1080/14780887.14782020.11769238.

Britt, E. and Blampied, N.M. (2015) Training Dietitians in Motivational Interviewing: A Pilot Study of the Effects on Dietitian and Patient Behaviour. *Motivational Interviewing: Training, Research, Implementation, Practice*, 1 (3), 7-12.

Brug, J., Spikmans, F., Aartsen, C., Breedveld, B., Bes, R. and Fereira, I. (2007) Training dietitians in basic motivational interviewing skills results in changes in their counseling style and in lower saturated fat intakes in their patients. *J Nutr Educ Behav*, 39 (1), 8-12.

Burke, L.M. (2001) Nutritional Practices of Male and Female Endurance Cyclists. *Sports Med*, 31 (7), 521-532.

Burke, L.M., Cox, G.R., Cummings, N.K. and Desbrow, B. (2001) Guidelines for Daily Carbohydrate Intake. Do athletes achieve them? *Sports Med*, 31 (4), 267-299.

Burke, L.M., Hawley, J.A., Wong, S.H. and Jeukendrup, A.E. (2011) Carbohydrates for training and competition. *Journal of sports sciences*, 29 (sup1), S17-S27.

Burke, L.M., Jeukendrup, A.E., Jones, A.M. and Mooses, M. (2019) Contemporary Nutrition Strategies to Optimize Performance in Distance Runners and Race Walkers. *Int J Sport Nutr Exerc Metab*, 29 (2), 117-129.

Burke, L.M. and Read, R.S. (1987) A study of carbohydrate loading techniques used by marathon runners. *Canadian Journal of Sport Sciences*, 12, 6-11.

Burke, L.M., Wood, C., Pyne, D.B., Telford, D.R. and Saunders, P.U. (2005) Effect of carbohydrate intake on half-marathon performance of well-trained runners. *Int J Sport Nutr Exerc Metab*, 15 (6), 573-589.

Bussau, V.A., Fairchild, T.J., Rao, A., Steele, P. and Fournier, P.A. (2002) Carbohydrate loading in human muscle: an improved 1 day protocol. *European Journal of Applied Physiology*, 87 (3), 290-295.

Costello, N., Deighton, K., Dyson, J., McKenna, J. and Jones, B. (2017) Snap-N-Send: A valid and reliable method for assessing the energy intake of elite adolescent athletes. *European Journal of Sport Science*, 17 (8), 1044-1055.

Cox, G.R., Snow, R.J. and Burke, L.M. (2010) Race-day carbohydrate intakes of elite triathletes contesting olympic-distance triathlon events. *International Journal of Sport Nutrition & Exercise Metabolism*, 20 (4), 299-306.

Cresswell, J.W. (2018) Qualitative Inquiry & Research Design: Choosing among Five Approaches In: (ed.) 4th ed. Thousand Oaks, Ca: SAGE.

Devlin, B.L. and Belski, R. (2015) Exploring General and Sports Nutrition and Food Knowledge in Elite Male Australian Athletes. *International journal of sport nutrition and exercise metabolism*, 25 (3), 225-232.

Devlin, B.L., Leveritt, M.D., Kingsley, M. and Belski, R. (2017) Dietary Intake, Body Composition, and Nutrition Knowledge of Australian Football and Soccer Players: Implications for Sports Nutrition Professionals in Practice. *Int J Sport Nutr Exerc Metab*, 27 (2), 130-138.

Doering, T.M., Reaburn, P.R., Cox, G. and Jenkins, D.G. (2016) Comparison of Postexercise Nutrition Knowledge and Postexercise Carbohydrate and Protein Intake between Australian Masters and Younger Triathletes. *International journal of sport nutrition and exercise metabolism*, 26 (4), 338-346.

Ebert, T.R., Martin, D.T., Stephens, B., McDonald, W. and Withers, R.T. (2007) Fluid and food intake during professional men's and women's road-cycling tours. *Int J Sports Physiol Perform*, 2 (1), 58-71.

Evans, R.R., Burnett, D.O., Kendrick, O.W., Macrina, D.M., Snyder, S.W., Roy, J.P.L. and Stephens, B.C. (2009) Developing Valid and Reliable Online Survey Instruments Using Commercial Software Programs. *Journal of Consumer Health On the Internet*, 13 (1), 42-52.

Furber, M.J.W., Roberts, J.D. and Roberts, M.G. (2017) A valid and reliable nutrition knowledge questionnaire for track and field athletes. *BMC Nutrition*, 3 (1), 36.

García-Rovés, P.M., Terrados, N., Fernández , S. and Patterson, A.M. (2000) Comparison of Dietary Intake and Eating Behavior of Professional Road Cyclists during Training and Competition. *International journal of sport nutrition and exercise metabolism*, 10 (1), 82-98.

Garcia-Roves, P.M., Terrados, N., Fernandez, S.F. and Patterson, A.M. (1998) Macronutrients intake of top level cyclists during continuous competition--change in the feeding pattern. *Int J Sports Med*, 19 (1), 61-67.

George, K., Batterham, A. and Sullivan, I. (2000) Validity in clinical research: a review of basic concepts and definitions. *Physical Therapy in Sport*, 1 (1), 19-27.

Gibbs, G. (1988) *Learning by doing: a guide to teaching and learning methods.* London: Further Education Unit.

Hansen, E.A., Emanuelsen, A., Gertsen, R.M. and Raadahl Sørensen, S.S. (2014) Improved Marathon Performance by In-Race Nutritional Strategy Intervention. *International Journal of Sport Nutrition & Exercise Metabolism*, 24 (6), 645-655.

Havemann, L. and Goedecke, J.H. (2008) Nutritional Practices of Male Cyclists Before and During an Ultraendurance Event. *International journal of sport nutrition and exercise metabolism*, 18, 551-566.

Hawley, J.A. (1997) Carbohydrate-Loading and Exercise Performance. *Sports Med*, 24 (2), 73-81.

Heaney, S., O'Connor, H., Michael, S., Gifford, J. and Naughton, G. (2011) Nutrition Knowledge in Athletes: A Systematic Review. *International Journal of Sport Nutrition & Exercise Metabolism*, 21 (3), 248-261.

Heaney, S., O'Connor, H., Naughton, G. and Gifford, J. (2008) Towards an Understanding of the Barriers to Good Nutrition for Elite Athletes. *International Journal of Sports Science & Coaching*, 3 (3), 391-401.

Heikura, I.A., LM, B., Mero, A.A. and Uusitalo, A.L.T. (2017a) Dietary Microperiodization in Elite Female and Male Runners and Race Walkers During a Block of High Intensity Precompetition Training. *International journal of sport nutrition and exercise metabolism*, 27 (4).

Heikura, I.A., Quod, M., Strobel, N., Palfreeman, R., Civil, R. and Burke, L.M. (2019) Alternate-Day Low Energy Availability During Spring Classics in Professional Cyclists. *Int J Sports Physiol Perform*, 1233-1243.

Heikura, I.A., Stellingwerff, T. and Burke, L.M. (2018) Self-Reported Periodization of Nutrition in Elite Female and Male Runners and Race Walkers. *Frontiers in physiology*, 9, 1732.

Heikura, I.A., Stellingwerff, T., Mero, A.A., Uusitalo, A.L.T. and Burke, L.M. (2017b) A Mismatch Between Athlete Practice and Current Sports Nutrition Guidelines Among Elite Female and Male Middle- and Long-Distance Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, 27 (4), 351-360.

Hoogervorst, D., van der Burg, N., Versteegen, J.J., Lambrechtse, K.J., Redegeld, M.I., Cornelissen, L.A.J. and Wardenaar, F.C. (2019) Gastrointestinal Complaints and Correlations with Self-Reported Macronutrient Intake in Independent Groups of (Ultra)Marathon Runners Competing at Different Distances. *Sports (Basel)*, 7 (6), 140.

Hoon, M., Haakonssen, E., Menaspà, P. and Burke, L. (2019) Racing weight and resistance training: perceptions and practices in trained male cyclists. *The Physician and Sportsmedicine*.

Hottenrott, K., Hass, E., Kraus, M., Neumann, G., Steiner, M. and Knechtle, B. (2012) A scientific nutrition strategy improves time trial performance by≈ 6% when compared with a self-chosen nutrition strategy in trained cyclists: a randomized cross-over study. *Applied Physiology, Nutrition, and Metabolism*, 37 (4), 637-645.

Impey, S.G., Hearris, M.A., Hammond, K.M., Bartlett, J.D., Louis, J., Close, G.L. and Morton, J.P. (2018) Fuel for the Work Required: A Theoretical Framework for Carbohydrate Periodization and the Glycogen Threshold Hypothesis. *Sports Medicine*, 48, 103-1048.

Jeukendrup, A. (2014) A step towards personalized sports nutrition: carbohydrate intake during exercise. *Sports Medicine*, 44 (1), 25-33.

Jeukendrup, A.E. (2004) Carbohydrate intake during exercise and performance. *Nutrition*, 20 (7-8), 669-677.

Karlsson, J. and Saltin, B. (1971) Diet, muscle glycogen, and endurance performance. *J Appl Physiol*, 31 (2), 203-206.

Karpinski, C.A., Dolins, K.R. and Bachman, J. (2019) Development and Validation of a 49-Item Sports Nutrition Knowledge Instrument (49-SNKI) for Adult Athletes. *Topics in Clinical Nutrition.*, 34 (3), 174-185.

Kerksick, C., Harvey, T., Stout, J., Campbell, B., Wilborn, C., Kreider, R., Kalman, D., Ziegenfuss, T., Lopez, H. and Landis, J. (2008) International Society of Sports Nutrition position stand: nutrient timing. *Journal of the International Society of Sports Nutrition*, 5 (17), 1.

Kerksick, C.M., Arent, S., Schoenfeld, B.J., Stout, J.R., Campbell, B., Wilborn, C.D., Taylor, L., Kalman, D., Smith-Ryan, A.E., Kreider, R.B., Willoughby, D., Arciero, P.J., VanDusseldorp, T.A., Ormsbee, M.J., Wildman, R., Greenwood, M., Ziegenfuss, T.N., Aragon, A.A. and Antonio, J. (2017) International society of sports nutrition position stand: nutrient timing. *J Int Soc Sports Nutr*, 14, 33.

Kimber, N.E., Ross, J.J., Mason, S.L. and Speedy, D.B. (2002) Energy balance during an ironman triathlon in male and female triathletes. *International journal of sport nutrition and exercise metabolism*, 12, 47-62.

Kline, P. (2000) *The Handbook of Psychological Testing*. 2nd ed. London: Routledge.

Kondric, M., Sekulic, D., Uljevic, O., Gabrilo, G. and Zvan, M. (2013) Sport Nutrition and Doping in Tennis: An Analysis of Athletes' Attitudes and Knowledge. *Journal of Sports Science and Medicine*, 12, 290-297.

Martin, C.K., Han, H., Coulon, S.M., Allen, H.R., Champagne, C.M. and Anton, S.D. (2009) A novel method to remotely measure food intake of free-living individuals in real time: the remote food photography method. *Br J Nutr*, 101 (3), 446-456.

Martin, M., Martin, D., Collier, G.R. and LM, B. (2002) Voluntary food intake by elite female cyclists during training and racing: influence of daily energy expenditure and body composition. *International Journal of Sport Nutrition & Exercise Metabolism*, 12 (3), 249-267.

Martinez, S., Aguilo, A., Rodas, L., Lozano, L., Moreno, C. and Tauler, P. (2018) Energy, macronutrient and water intake during a mountain ultramarathon event: The influence of distance. *Journal of sports sciences*, 36 (3), 333-339.

Masson, G. and Lamarche, B. (2016) Many non-elite multisport endurance athletes do not meet sports nutrition recommendations for carbohydrates. *Applied Physiology, Nutrition & Metabolism*, 41 (7), 728-734.

Matthews, K.L., Baird, M. and Duchesne, G. (2018) Using Online Meeting Software to Facilitate Geographically Dispersed Focus Groups for Health Workforce Research. *Qualitative Health Research*, 28 (10), 1621–1628.

McLeman, L.A., Ratcliffe, K. and Clifford, T. (2019) Pre- and post-exercise nutritional practices of amateur runners in the UK: are they meeting the guidelines for optimal carbohydrate and protein intakes? *Sport Sciences for Health*, 15, 511-517.

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., Eccles, M., Cane, J. and Wood, C. (2013) The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med*, 46 (1), 81-95.

Michie, S., van Stralen, M.M. and West, R. (2011) The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci*, 6, 42.

Mujika, I. (2018) Case Study: Long-Term Low Carbohydrate, High Fat Diet Impairs Performance and Subjective Wellbeing in a World-Class Vegetarian Long-Distance Triathlete. *International journal of sport nutrition and exercise metabolism*, 29 (3), 339-344.

Muros, J.J., Sanchez-Munoz, C., Hoyos, J. and Zabala, M. (2019) Nutritional intake and body composition changes in a UCI World Tour cycling team during the Tour of Spain. *Eur J Sport Sci*, 19 (1), 86-94.

Nichols, P.E., Jonnalagadda, S.S., Rosenbloom, C.A. and Trinkaus, M. (2005) Knowledge, Attitudes, and Behaviors Regarding Hydration and Fluid Replacement of Collegiate Athletes. *International journal of sport nutrition and exercise metabolism*, 15, 515-527.

Nikolaidis, P.T., Veniamakis, E., Rosemann, T. and Knechtle, B. (2018) Nutrition in Ultra-Endurance: State of the Art. *Nutrients*, 10 (12).

Nunes, C.L., Matias, C.N., Santos, D.A., Morgado, J.P., Monteiro, C.P., Sousa, M., Minderico, C.S., Rocha, P.M., St-Onge, M.P., Sardinha, L.B. and Silva, A.M. (2018) Characterization and Comparison of Nutritional Intake between Preparatory and Competitive Phase of Highly Trained Athletes. *Medicina (Kaunas)*, 54 (3), 41.

Parnell, J.A., Lafave, H., Wagner-Jones, K., Madden, R.F. and Erdman, K.A. (2019) Development of a questionnaire to assess dietary restrictions runners use to mitigate gastrointestinal symptoms. *J Int Soc Sports Nutr*, 16 (1), 11.

Pelly, F.E. and Wright, H.H. (2021) Outcomes of a nutrition service provided by dietitians at a major multi-cultural competition event: An observational study. *Nutr Diet*, 78 (2), 183-191.

Pfeiffer, B., Stellingwerff, T., Hodgson, A.B., Randell, R., Pottgen, K., Res, P. and Jeukendrup, A.E. (2012) Nutritional Intake and Gastrointestinal Problems during Competitive Endurance Events. *Med Sci Sports Exer*, 44 (2), 344-351.

Pugh, J.N., Kirk, B., Fearn, R., Morton, J.P. and Close, G.L. (2018) Prevalence, Severity and Potential Nutritional Causes of Gastrointestinal Symptoms during a Marathon in Recreational Runners. *Nutrients*, 10 (7), 811.

Randall, W.L. and Phoenix, C. (2009) The problem with truth in qualitative interviews: reflections from a narrative perspective. *Qualitative Research in Sport and Exercise*, 1 (2), 125-140.

Rash, C.L., Malinauskas, B.M., Duffrin, M.W., Barber-Heidal, K. and Overton, R.F. (2008) Nutrition-related knowledge, attitude, and dietary intake of college track athletes. *Sport J*, 11, 48-54.

Regmi, P.R., Waithaka, E., Paudyal, A., Simkhada, P. and van Teijlingen, E. (2016) Guide to the design and application of online questionnaire surveys. *Nepal Journal of Epidemiology*, 6 (4), 640-644.

Rehrer, N.J., Hellemans, I.J., Rolleston, A.K., Rush, E. and Miller, B.F. (2010) Energy intake and expenditure during a 6-day cycling stage race. *Scand J Med Sci Sports*, 20, 609-618.

Robins, A. and **Hetherington, M.M.** (2005) A Comparison of Pre-Competition Eating Patterns in a Group of Non-Elite Triathletes. *International journal of sport nutrition and exercise metabolism*, 15 (4), 442-457.

Ross, M.L., Stephens, B., Abbiss, C.R., Martin, D.T., Laursen, P.B. and Burke, L.M. (2014) Fluid balance, carbohydrate ingestion, and body temperature during men's stage-race cycling in temperate environmental conditions. *Int J Sports Physiol Perform*, 9 (3), 575-582.

Rothschild, J.A., Kilding, A.E. and Plews, D.J. (2020a) Pre-Exercise Nutrition Habits and Beliefs of Endurance Athletes Vary by Sex, Competitive Level, and Diet. *J Am Coll Nutr*, Online ahead of print, 1-12.

Rothschild, J.A., Kilding, A.E. and Plews, D.J. (2020b) What Should I Eat before Exercise? Pre-Exercise Nutrition and the Response to Endurance Exercise: Current Prospective and Future Directions. *Nutrients*, 12 (11).

Sanchez-Munoz, C., Zabala, M. and Muros, J.J. (2016) Nutritional intake and anthropometric changes of professional road cyclists during a 4-day competition. *Scand J Med Sci Sports*, 26 (7), 802-808.

Saris, W.H., Brouns, F., van Erp-Baart, M.A., Westerterp, K.R. and Ten Hoor, F. (1983) Study on food intake and energy expenditure during extreme sustained exercise: The Tour de France. *International Journal of Sports Medicine*, 10 (S1), S26-S31.

Schon, D. (1983) *The reflective practitioner: How professionals think in action*. London: Temple Smith.

Sedek, R. and Yun Yih, T. (2014) Dietary habits and nutrition knowledge among athletes and non-athletes in National University of Malaysia (UKM). *Pakistan Journal of Nutrition*, 13 (12), 752-759.

Sherman, W.M., Costill, D.L., Fink, W.J. and Miller, J.M. (1981) Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilization during performance. *Int J Sports Med*, 2 (2), 114-118.

Smith, B. (2017) Generalizability in qualitative research: misunderstandings, opportunities and recommendations for the sport and exercise sciences. *Qualitative Research in Sport, Exercise and Health*, 10 (1), 137-149.

Smith, B. and McGannon, K.R. (2017) Developing rigor in qualitative research: problems and opportunities within sport and exercise psychology. *International Review of Sport and Exercise Psychology*, 11 (1), 101-121.

Sparks, I.M., Janse van Rensburg, D.C., Fletcher, L. and Jansen van Rensburg, A. (2018) A cross-sectional study of 2550 amateur cyclists shows lack of knowledge regarding relevant sports nutrition guidelines. *South African Journal of Sports Medicine*, 30 (1), 1-6.

Spendlove, J.K., Heaney, S.E., Gifford, J.A., Prvan, T., Denyer, G.S. and O'Connor, H.T. (2011) Evaluation of general nutrition knowledge in elite Australian athletes. *British Journal of Nutrition*, 107 (12), 1871-1880.

Spronk, I., Heaney, S.E., Prvan, T. and O'Connor, H.T. (2015) Relationship Between General Nutrition Knowledge and Dietary Quality in Elite Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, 25 (3), 243-251.

Stables, R.G., Kasper, A.M., Sparks, S.A., Morton, J.P. and Close, G.L. (2021) An Assessment of the Validity of the Remote Food Photography Method (Termed Snap-N-Send) in Experienced and Inexperienced Sport Nutritionists. *Int J Sport Nutr Exerc Metab*, 31 (2), 125-134.

Stellingwerff, T. and Cox, G.R. (2014) Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations. *Applied Physiology, Nutrition & Metabolism*, 39 (9), 998-1011.

Taber, K.S. (2017) The Use of Cronbach’s Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, 48 (6), 1273-1296.

Tam, R., Beck, K.L., Gifford, J.A., Flood, V.M. and O'Connor, H.T. (2020) Development of an Electronic Questionnaire to Assess Sports Nutrition Knowledge in Athletes. *J Am Coll Nutr*, 39 (7), 636-644.

Tam, R., Beck, K.L., Manore, M.M., Gifford, J., Flood, V.M. and O'Connor, H. (2019) Effectiveness of Education Interventions Designed to Improve Nutrition Knowledge in Athletes: A Systematic Review. *Sports Med*, 49 (11), 1769-1786.

Tavakol, M. and Dennick, R. (2011) Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2, 53-55.

Thomas, D.T., Erdman, K.A. and Burke, L.M. (2016a) American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Med Sci Sports Exerc*, 48 (3), 543-568.

Thomas, D.T., Erdman, K.A. and Burke, L.M. (2016b) Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. *Journal of the Academy of Nutrition and Dietetics*, 116 (3), 501-528.

Thurecht, R. and Pelly, F. (2020) Key Factors Influencing the Food Choices of Athletes at two Distinct Major International Competitions. *Nutrients*, 12 (4).

Thurecht, R.L. and Pelly, F.E. (2019) Development of a New Tool for Managing Performance Nutrition: The Athlete Food Choice Questionnaire. *Int J Sport Nutr Exerc Metab*, 29 (6), 620-627.

Tollefson, J., Usher, K., Francis, D. and Owens, J. (2014) What you ask is what you get: Learning from interviewing in qualitative research. *Contemporary Nurse*, 10 (3-4), 258-264.

Tracy, S.J. (2010) Qualitative Quality: Eight “Big-Tent” Criteria for Excellent Qualitative Research. *Qualitative Inquiry*, 16 (10), 837-851.

Trainor, L.R. and Bundon, A. (2020) Developing the craft: reflexive accounts of doing reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 1-22.

Trakman, G.L., Brown, F., Forsyth, A. and Belski, R. (2019a) Modifications to the nutrition for sport knowledge questionnaire (NSQK) and abridged nutrition for sport knowledge questionnaire (ANSKQ). *J Int Soc Sports Nutr*, 16 (1), 26.

Trakman, G.L., Forsyth, A., Devlin, B.L. and Belski, R. (2016) A Systematic Review of Athletes' and Coaches' Nutrition Knowledge and Reflections on the Quality of Current Nutrition Knowledge Measures. *Nutrients*, 8 (9).

Trakman, G.L., Forsyth, A., Hoye, R. and Belski, R. (2017) The nutrition for sport knowledge questionnaire (NSKQ): development and validation using classical test theory and Rasch analysis. *J Int Soc Sports Nutr*, 14, 26.

Trakman, G.L., Forsyth, A., Hoye, R. and Belski, R. (2018) Development and validation of a brief general and sports nutrition knowledge questionnaire and assessment of athletes' nutrition knowledge. *J Int Soc Sports Nutr*, 15, 17.

Trakman, G.L., Forsyth, A., Hoye, R. and Belski, R. (2019b) Australian team sports athletes prefer dietitians, the internet and nutritionists for sports nutrition information. *Nutr Diet*, 76 (4), 428-437.

van Loon, L.J., Saris, W.H., Kruijshoop, M. and Wagenmakers, A.J. (2000) Maximizing postexercise muscle glycogen synthesis: carbohydrate supplementation and the application of amino acid or protein hydrolysate mixtures. *The American Journal of Clinical Nutrition*, 72 (1), 106-111.

Wardenaar, F.C., Dijkhuizen, R., Ceelen, I.J., Jonk, E., de Vries, J.H., Witkamp, R.F. and Mensink, M. (2015) Nutrient Intake by Ultramarathon Runners: Can They Meet Recommendations? *Int J Sport Nutr Exerc Metab*, 25 (4), 375-386.

Wardenaar, F.C., Hoogervorst, D., van der Burg, N., Versteegen, J., Yoo, W. and Tasevska, N. (2019) Validity of a Food and Fluid Exercise Questionnaire for Macronutrient Intake during Exercise against Observations. *Nutrients*, 11 (10), 2391.

Welsh, E. (2002) Dealing with Data: Using NVivo in the Qualitative Data Analysis Process. *Forum: Qualitative Social Research*, 3 (2), 26.

Wilson, P.B. (2016) Nutrition behaviors, perceptions, and beliefs of recent marathon finishers. *Phys Sportsmed*, 44 (3), 242-251.

Worme, J.D., Doubt, T.J., Singh, A., Ryan, C.J., Moses, F.M. and Deuster, P.A. (1990) Dietary patterns, gastrointestinal complaints, and nutrition knowledge of recreational triathletes. *Am J Clin Nutr*, 51 (4), 690-697.

Zinn, C., Schofield, G. and Wall, C. (2005) Development of a psychometrically valid and reliable sports nutrition knowledge questionnaire. *Journal of Science and Medicine in Sport*, 8 (3), 346-351.

Chapter 9

Appendices

Appendix 1. Carbohydrate for Endurance Athletes in Competition Questionnaire (CEAC-Q)

Please select the correct answer (s) to each question. If you are unsure, do not guess, please select 'unsure'.

SECTION 1: CARBOHYDRATE STORAGE AND METABOLISM		**Score: __/ 20**
1. Which factor(s) influence how much carbohydrate our body uses during exercise? *(Select all that apply)*	**Points (each)**	**_/ 4**
Exercise intensity	1	
Exercise duration	1	
Environmental factors (temperature, altitude)	1	
Training status (fitness level, years of training)	1	
The carbohydrate use during exercise is not affected by any of these factors	0	
Unsure	0	
2. Which of the following carbohydrate related factors contribute to fatigue during exercise? *(select ONE answer)*	**Points**	**_ /4**
Low blood sugar levels only	0	
Low muscle glycogen stores only	0	
Low blood sugar and low muscle glycogen stores	4	
Carbohydrate stores do not contribute to fatigue during exercise	0	
Unsure	0	
3. In a carbohydrate loaded state, carbohydrate is stored in the body as: *(select one answer)*	**Points**	**_/4**
Muscle glycogen only	0	
Liver glycogen only	0	
Muscle glycogen (80%) and liver glycogen (20%)	4	
Muscle glycogen (20%) and liver glycogen (80%)	0	
Carbohydrate is not stored in the body	0	
Unsure	0	
4. In a carbohydrate loaded state, total carbohydrate storage in the body is approximately: *(select one answer)*	**Points**	**_/4**
< 200 g	0	
200 - 400 g	0	
400 – 600 g	4	
Carbohydrate is not stored in the body	0	
Unsure	0	
5. Which source of carbohydrate stores is used to maintain normal blood sugar during exercise? *(select one answer)*	**Points**	**_/4**
Muscle glycogen only	0	
Liver glycogen only	4	
Muscle and liver glycogen	0	
Carbohydrate stores are not used to maintain blood sugar during exercise	0	
Unsure	0	

SECTION 2: PRE-COMPETITION CARBOHYDRATE LOADING	**Score: __/ 20**

6. Carbohydrate loading in the days before a competitive endurance event can increase endurance performance by? (*select one answer*)	**Points**	**_/ 4**
Carbohydrate loading cannot increase endurance performance	0	
Increasing maximal speed or power output during prolonged exercise	0	
Delaying the onset of fatigue during the late stages of prolonged exercise	4	
Unsure	0	
7. Carbohydrate loading to maximise glycogen stores is most effective in improving performance in competitive events lasting: (*select one answer)*	**Points**	**_ /4**
Less than 60 minutes	0	
60 - 90 minutes	0	
More than 90 minutes	4	
Carbohydrate loading is unnecessary	0	
Unsure	0	
8. When carbohydrate loading before competition, the recommended range of carbohydrate intake per day is? *(assuming exercise activity the day before is minimal; select one answer)*	**Points**	**_/4**
Less than 4 g per kilogram body mass	0	
5 - 8 g per kilogram body mass	0	
9 - 12 g per kilogram body mass	4	
More than 12 g per kilogram body mass	0	
Carbohydrate loading is never required	0	
Unsure	0	
9. When competing WITHOUT carbohydrate loading, the recommended range of carbohydrate intake per day is? *(assuming exercise activity the day before is minimal; select one answer)*	**Points**	**_/4**
Less than 4 g per kilogram body mass	0	
5 - 8 g per kilogram body mass	4	
9 - 12 g per kilogram body mass	0	
More than 12 g per kilogram body mass	0	
Eating carbohydrate is never required before exercise	0	
Unsure	0	
10. To maximise muscle glycogen stores, carbohydrate loading (in combination with a tapering of training loads) is best followed for: *(select one answer)*	**Points**	**_/4**
12 - 24 hours before a competition	0	
24 - 48 hours before a competition	4	
A week before a competition	0	
Carbohydrate loading is never required	0	
Unsure	0	

SECTION 3: BEFORE COMPETITION CARBOHYDRATE MEAL		Score: __/ 20
11. How much carbohydrate should a meal eaten before competition contain (in grams per kilogram body mass)? *(select one answer)*	**Points**	**_/ 4**
Less than 1 g per kg body mass	0	
1 - 4 g per kg body mass	4	
More than 4 g per kg body mass	0	
Eating carbohydrate is never required before exercise	0	
Unsure	0	
12. When is eating a meal or snack rich in carbohydrate likely to improve performance? *(select one answer)*	**Points**	**_ /4**
Before competition lasting LESS than 60 minutes	0	
Before competition lasting MORE than 60 minutes	0	
Never	0	
Always	4	
Unsure	0	
13. Eating a meal rich in carbohydrate in the hours before competition specifically: *(select one answer)*	**Points**	**_/4**
To increase MAINLY muscle glycogen stores	0	
To increase MAINLY liver glycogen stores	4	
Increase both muscle and liver glycogen stores	0	
Eating carbohydrate before competition has no significant effect on carbohydrate stores	0	
Unsure	0	
14. A meal rich in carbohydrate should be eaten how many hours before competition *(select one answer)*	**Points**	**_/4**
Less than 1 hour before	0	
1 - 4 hours before	4	
More than 4 hours before	0	
Eating carbohydrate is never required before exercise	0	
Unsure	0	
15. Which of the following statements is correct regarding carbohydrate intake and gastrointestinal distress: *(select one answer)*	**Points**	**_/4**
Eating carbohydrate before and during competition always results in gastrointestinal distress	0	
The gut can NOT be trained to tolerate carbohydrate before and during competition	0	
The gut CAN be trained to tolerate carbohydrate before and during competition	4	
Unsure	0	

SECTION 4: CARBOHYDRATE DURING COMPETITION		Score: __/ 20
16. Consuming carbohydrate during exercise can improve endurance performance by: *(Select all that apply)*	**Points (each)**	**_/ 4**
Maintaining blood sugar levels	1	
Increasing the amount of free glucose available for contracting muscle	1	
Reducing the energy cost of exercise	1	
Stimulating the central nervous system	1	
Eating carbohydrate during exercise does not improve endurance performance	0	
Unsure	0	
17. Holding a small amount of a carbohydrate drink in the mouth for 10-15 seconds (e.g. mouth rinsing the drink) during competition: *(select one answer)*	**Points**	**_ /4**
Can act as a stimulant and improve performance even if not swallowed	4	
Only improves performance if swallowed	0	
Has no effect on performance	0	
Has a negative impact on performance	0	
Eating carbohydrate is never required during exercise	0	
Unsure	0	

18. How much carbohydrate is recommended per hour during competition lasting: *(select one option per duration)*		**Points per column**	
	< 1 hour competition	– 2.5 h competition	> 2.5 h competition	_ / 4
None	0	0	0	
Mouth rinse or < 30g	1.33	0	0	
30 – 60 g per hour	0	1.33	0	
60- 90 g per hour	0	0	1.33	
> 90 g per hour	0	0	0	
Unsure	0	0	0	

19. If you take either a sports drink or energy gel containing 25g carbohydrate during exercise, would there be any difference in the amount of carbohydrate that is used by the body? *(when equal amounts of fluid is taken; select one answer)*	**Points**	**_/4**
Yes - the sports drink would allow your body to use more carbohydrate than the gel	0	
Yes - the gel would allow your body to use more carbohydrate than the drink	0	
No, there would be no difference	4	
Eating carbohydrate is never required during exercise	0	
Unsure	0	

20. How much carbohydrate consumed per hour during competition is your body able to absorb and use depending on the source? *(Select one option per column)*		**Points**	
	Single source of carbohydrate (e.g. glucose only)	Multiple sources of carbohydrate (e.g. glucose + fructose)	**_/4**
None	0	0	
30 – 60 g per hour	2	0	
60 – 90 g per hour	0	2	
> 90 g per hour	0	0	
Unsure	0	0	

SECTION 5: CARBOHYDRATE FOR POST-COMPETITION RECOVERY.		Score: __/ 20
21. After glycogen depleting exercise, muscle glycogen stores recover the fastest when carbohydrate is eaten *(select one answer)*	**Points**	**__/ 4**
Early after exercise (within 0 - 4 hours)	4	
Late after exercise (after > 4 hours)	0	
It doesn't change with time	0	
Eating carbohydrate after exercise does not influence the recovery rate of carbohydrate stores	0	
Unsure	0	
22. In the first four hours after glycogen depleting exercise, how much carbohydrate should you eat to maximise recovery of muscle glycogen stores? *(select one answer)*	**Points**	**_ /4**
< 0.5 g per kg body mass per hour	0	
0.5 – 1.0 g per kg body mass per hour	0	
1.0 - 1.2 g per kg body mass per hour	4	
> 1.2 g per kg body mass per hour	0	
The amounts consumed do not influence the recovery rate of carbohydrate stores	0	
Unsure	0	
23. With optimal carbohydrate intake, how long would it take to fully restore muscle glycogen stores to pre-exercise levels after glycogen depleting exercise? *(select one answer)*	**Points**	**_/4**
0 - 12 hours	0	
12 - 24 hours	4	
24 - 72 hours	0	
Eating carbohydrate is not required after exercise to increase the recovery rate of carbohydrate stores	0	
Unsure	0	
24. To maximise recovery of muscle glycogen stores within 8 hours post-exercise: *(select one answer)*	**Points**	**_/4**
Moderate to high glycaemic index (GI) carbohydrates are superior to low GI	4	
Low glycaemic index carbohydrates are superior to moderate to high GI	0	
There is no difference between high or low glycaemic index carbohydrates	0	
Eating carbohydrate is not required after exercise to increase the recovery rate of carbohydrate stores	0	
Unsure	0	
25. Can eating protein, in addition to carbohydrate, help to maximise muscle glycogen recovery after exercise? *(select one answer)*	**Points**	**_/4**
Only if the amount of carbohydrate is sub-optimal (< 1.2 g/kg/h) and some protein is eaten at the same time (~0.2 g/kg/h)	4	
Only if the amount of carbohydrate is very small (~0.1 g/kg) and a large amount of protein is eaten at the same time (> 0.4 g/kg/h)	0	
Eating protein together with carbohydrate has no additional benefit for restoring muscle glycogen	0	
Eating carbohydrate is not required after exercise to increase the recovery rate of carbohydrate stores	0	
Unsure	0	

CEAC-Q Test-Retest change in knowledge and self-directed learning questions

Change in knowledge questions were only used for test-retest reliability for Study 1.

CHANGE IN KNOWLEDGE
Since completing this questionnaire the first time, has your level of sports nutrition knowledge changed?
Same
Increased
Has completing this questionnaire motivated you to learn more about sports nutrition for competition?
Yes
No
If your sports nutrition knowledge has changed since first completing this questionnaire, please share how or why it has changed?
Open ended response to explain why

CEAC-Q Scoring Sheet

Carbohydrate for Endurance Athletes during Competition Questionnaire Scoring Sheet	**Total CEAC-Q Score __ / 100**
SECTION 1: Carbohydrate storage and metabolism	__ / 20
SECTION 2: Pre competition carbohydrate loading	__ / 20
SECTION 3: Before competition carbohydrate meal	__ / 20
SECTION 4: Carbohydrate during competition	__ / 20
SECTION 5: Carbohydrate for post-competition recovery	__ / 20

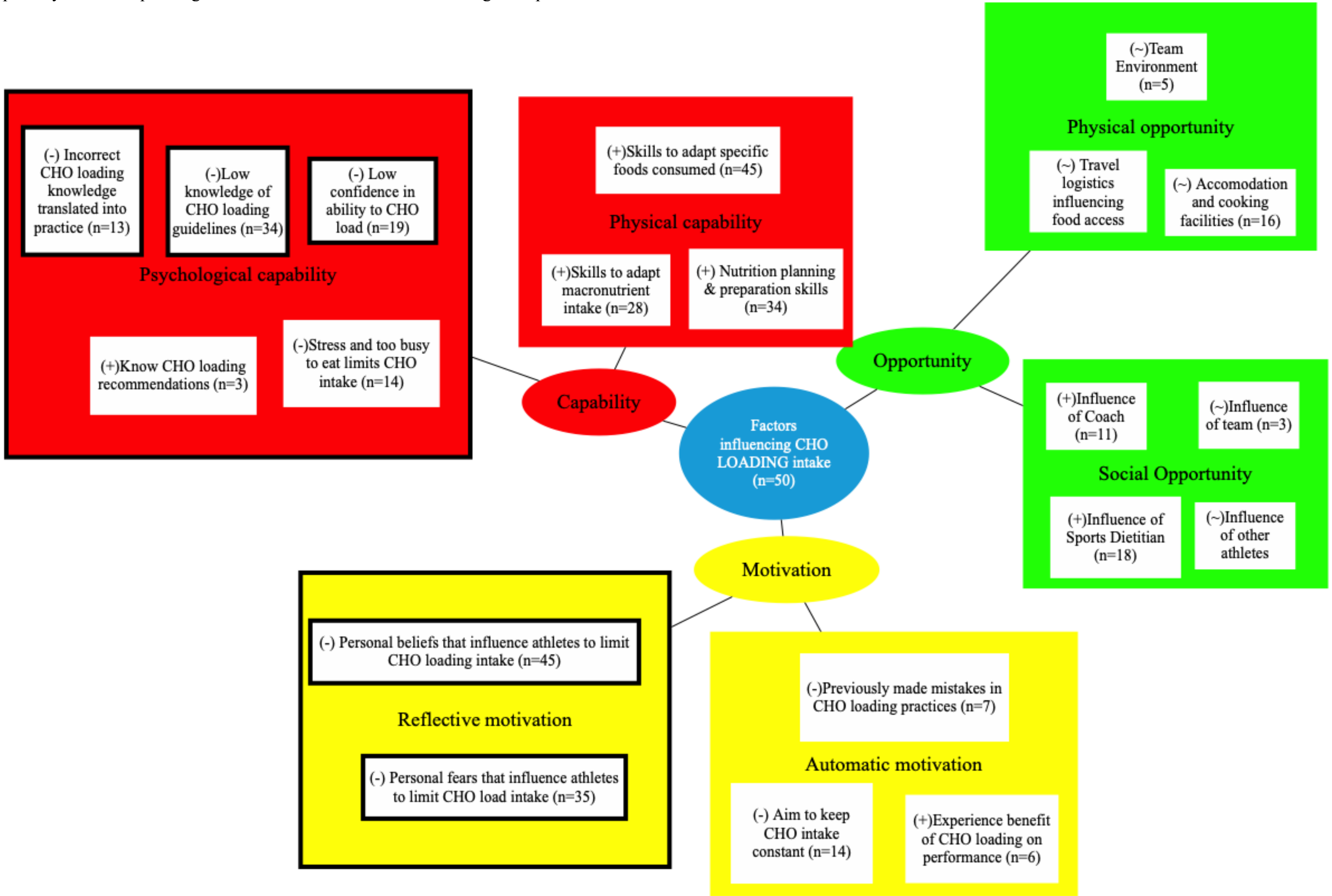
Appendix 2. Study 4 Interview question guide

Using a semi-structured approach, the main questions (or similar) were asked, with the points beneath each question used as potential factors to navigate and prompt during the interview.

1. How did your race go over the weekend?
2. Describe to me your current dietary habits (carbohydrate) starting the day before the race, up to the race?
    i. Breakfast through to bed
    ii. Why do you eat this food at this time?
3. What food/drink did you consume during the race?
    i. What was your nutrition plan?
    ii. What help have you had with creating that plan? E.g. coach nutritionist
    iii. What are the most important factors for your nutrition plan?
    iv. What influences you not following your plan?
    v. Have you ever tried or tested your nutrition plan in training?
4. Carbohydrate loading, what does that mean to you? *Following factors were prompted:*
    i. Did you use carbohydrate loading yourself?
    ii. What method(s) do you use?
    iii. How many days?
    iv. How much carbohydrate?
    v. How hard do you find it mentally and physically on your body?
    vi. Thoughts on low carbohydrate high fat diets during competition?
5. Is there anything that influences the foods that you eat the day before and during a race? *Following potential factors were prompted: peers, media, cost, time, race distance or time to finish, travel, race intensity, weather*
6. What do you think about the food provided at races by the organiser?
7. Compared to other athletes, how would you rate your nutrition knowledge on a score of 1 to 10?

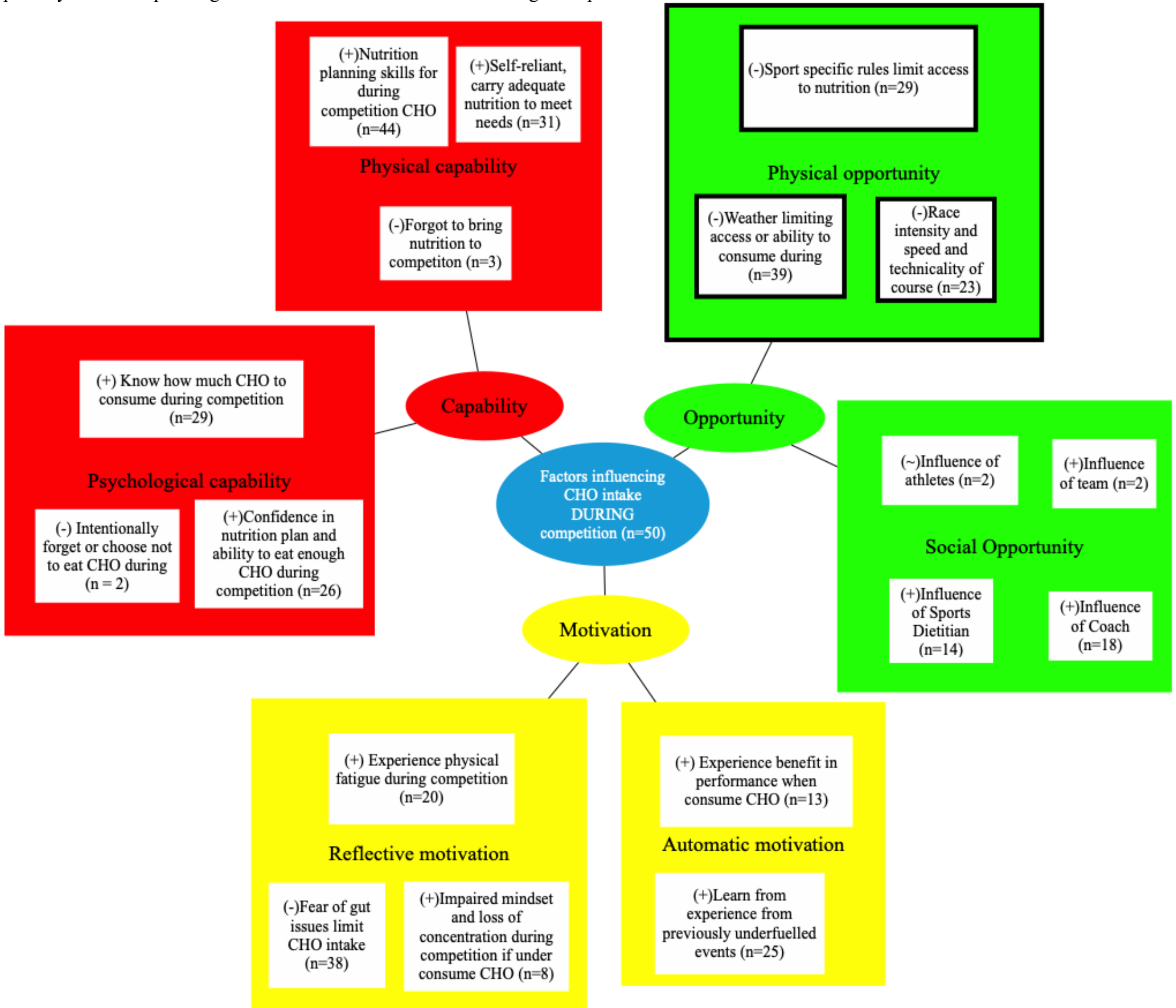
Appendix 3. Factors influencing carbohydrate loading intake of endurance athletes 24 h prior to competition

Each factor categorised as having a positive (+), negative (-) or neutral (~) impact on carbohydrate loading intake during competition according to the COM-B and TDF Framework, where factors in bold represent primary themes explaining mismatch observed between knowledge and practice.



Appendix 4. Factors influencing carbohydrate intake of endurance athletes during competition

Each factor categorised as having a positive (+), negative (-) or neutral (~) impact on carbohydrate loading intake during competition according to the COM-B and TDF Framework, where factors in bold represent primary themes explaining mismatch observed between knowledge and practice.



Appendix 5. Factors influencing carbohydrate loading intake of endurance athletes 24 h prior to competition

Raw Data Quotes	Subtheme	General dimension
PHYSICAL CAPABILITY TO CARBOHYDRATE LOAD PRIOR TO COMPETITION		
"I'll just naturally move more towards carbohydrates, a little bit less fibre, a little bit less protein. And definitely I try to limit my fat, my fat intake the day before, and you know, probably the two days out, but just because I start to prioritize those carbohydrates a little bit more." **15TPF**	(+) Increase carbohydrate content of meals (17) (+) Reduce fat (4), fibre (24) or protein content of meals (8)	(+) Skills to adapt macronutrient intake of diet to account for CHO loading (28)
"I'll eat a little bit more than I tend to like usually, but not much. But just instead of eating a bit more of a protein. And maybe like greens and stuff I'll have, like, you know, not as much like salad, let's say and just have a bit more rice instead and like just, yeah, eat more carbs versus like, protein and everything else." **37CPM**	(+) Reduce vegetable content of meals (n=21) (+) Focus on portions of pasta (n=31) or rice in meals (26)	(+) Skills to adapt specific foods consumed to account for CHO loading (45)
"I guess it varies depending on the accommodation situation and food options of the accommodation." **13TPF** "*I just take them with me cos they're easy to carry. So that's what I usually do. As a backup, I'll take a rice and two cans of tuna to most of my races…Yeah, I always take emergency food so if in doubt, tuna and rice."* **13TPF** *"mostly I don't usually take much else out cos yeah to be fair like most places it's pretty easy to get hold of whatever."* **42TAF** *"when I first was trying it, so a lot times I have to actually track it like enough in My Fitness Pal or some app, some nutrition app. Food tracker, because it really yeah, it's so much"* **1CPF**	(+) Decision to plan and take own food depends on event and accommodation (11) (+) Take own food to event (24) (-) Don't take own food, buy food at the event (8) (+) Use a nutrition tracker to monitor food intake	(~) Nutrition planning & preparation skills (34)

"I think I pretty much everything probably stems from a lack of planning, like I kind of know, I think I have a reasonable idea of what to eat and when to eat it. I'm just really bad at remembering it or making a plan." **Athlete 4CAM**	(-) Unorganised, forget and don't plan food or meals to consume before the event (4)	
PSYCHOLOGICAL CAPABILITY TO CARBOHYDRATE LOAD PRIOR TO COMPETITION		
"I'd been advised to try and get between sort of 8 and 10.. grams of carbohydrates to each kilo of body weight was what I'd been given as a target. I was probably slightly on the lower end of that scale. So I think my race, my weight at that point was about 64 kilos, maybe 65 kilos. And each day I think I was getting about between 550 and 600g of carbohydrate" **Athlete 18RAM**	(+) Know CHO loading protocols g.kg (2) Know CHO loading absolute amounts (2)	Know current CHO loading protocols (3)
"*I probably didn't hit my carbs that I would have ideally had the day before and my timing was a bit off. I had a late lunch, then that didn't make me hungry for dinner. And so delaying the lunch, they're not having a proper dinner. I didn't quite hit the carbs that I would have liked to have hit. I don't think it was drastically low. But yeah, that's probably the only thing that I thought… I wasn't as prepared as I thought it was."* **Athlete TPF** *"it was actually quite a busy day for me. Normally, I would have eaten even more sugar than I did. But I have a lot of things to do, and I was a bit stressed. So I didn't eat that much during the day as I probably normally would have."* **35TPM** *"I often find that I don't get hungry* [the day before competition]. *Like I, I almost don't feel like I need food, so I forget to eat for really long periods of time, which is obviously not ideal.* **4CAM**	(-) Poor timing of meals the day before limiting CHO intake (-) Too busy or stressed the day before competition to eat optimally. (-) Poor hunger cues to eat the day before competition and forget to eat the day before competition	Stress or poor hunger cues limit CHO load intake (14)
PHYSICAL OPPORTUNITY TO CARBOHYDRATE LOAD PRIOR TO COMPETITION		
"Because it's pre-race you've got so I think I'm too distracted and I'm not planned enough because of everything else that's going on with getting to the race, the setting up for the race	(-) Distractions with registration, setting up for the race limiting intake	(-) Travel logistics influencing food access

with registering. I think I fail in my, my plan to be prepared because you're not at home, you don't have access to the foods that you want all the time, and you don't sometimes have enough time. So I think I should be a little bit more prepared and planned and know that, you know, getting more carbs into me, the two days or so beforehand, it's going to be far more beneficial for me." **16TPF**		the day before competition (34)
"Depends on the race and accommodation. If I've got an Airbnb, I'd probably make my own food. But if I'm staying in a hotel, I'd be eating out unless, unless I was in an area that I wasn't sure of the food." **13TPF** "*The Dinners were probably slightly less than what I usually have. Probably by about a half... Or about a third. Just because there were so many guys there and they kind of undercooked a little bit so we kind of restricted in how much we could have."* **32CAF** *"we ate out a lot more. So you know, four of the five nights we ate in a restaurant, I wouldn't do if I was by myself. And to be honest, I wouldn't normally do even if I was with people. Like I'd suggest cooking, but cooking for 10 people is quite hard work."* **48TPF**	(~) Race location and accommodation influencing food choices and options (~) Influence of others cooking impacting food intake (~) Eating at restaurants or cafes versus cooking influencing food choices and portions	(~) Accommodation and cooking facilities influence food intake (16)
"with the team that you're with all year, then there's like, yeah, you have like a normal. And then also, I think it's Yeah, routine that everyone kind of understands it on the same thing. So then with the national team, it's a little bit more unpredictable. Like what will they provide? And then like, are they catering to me? Are they catering to another athlete?" **1CPF** *"when you're traveling and you're always in a different place, like different food and everything, you're always kind of adjusting a little bit and trying to get your hands on what you're used to or, what you, you know, you should eat and you do eat when you do race and you're, let's say like home or whatever. So that's always kind of a challenge,"* **37CPM**	(-) Unpredictable food access and intake (~) Need to be adaptable with food intake when racing due to team	(-) Team environment influences food access (5)

"I guess, high up men's teams, and some women's teams have a chef that goes with them. So actually, they are consistent, or the race buffet is very specific, or it's okay for them to ask for extra food. But like so often on smaller women's teams, like, you don't have you're not allowed to buy snacks like that. The team can't afford and then most of us don't get paid enough. Like we're not buying our own food, because we're too poor, to justify buying our own food when we can get it for free from the team" **7CPF**	(-) Difference between provision of men and women's cycling teams	
SOCIAL OPPORTUNITY TO CARBOHYDRATE LOAD PRIOR TO COMPETITION		
"I know my diet is actually generally very high in fibre. The sports nutritionist was like are you sure you're having this much fibre? It was excessive, excessive amount. So I do cut that down a little bit. Probably the two days and the day before the race." **16TPF** *"Yeah she [nutritionist] she writes the meal plans and the grocery list and we just follow that.. So now I sort of I spent a lot of time last year, sort of practicing before big ride days, how much I would sort of eat, how much my body can handle within the realms of what our nutritionist sort of said we needed to have. How many carbs or whatever."* **19CPF** *"I'd worked with the nutritionist, and all we did was talk about how to fuel the day before the race and during the race. And so… kind of having these like, carbohydrate guidelines, or like, try to aim to get so then yeah, usually before any one-day race, I'll always try to get that kind of carb, um, Yeah, hit the carb goals, I guess… I can't remember. I always have to look at it. But I think it's like 600 grams of carbs the day [before]."* **1CPF**	(+) Advice to change food content and specific nutrients (+) Provides specific meal plan to follow for CHO loading (+) Provided specific CHO loading targets by dietitian/nutritionist	(+) Influence of a sports dietitian on foods planned and consumed (18)
"I think I'd been advised to try and get between sort of 8 and 10, 8 and 10 grams of carbohydrates to each kilo of body weight was what I'd been given as a target. I was probably slightly on the lower end of that scale. So I think my, my race, my weight at that	(+) Coach provided clear guidelines or recommendations of CHO intake for loading	(+)Influence of the coach on foods planned and consumed (11)

point was about 64 kilos, maybe 65 kilos. And each day, I think I was getting about between 550 and 600 grams of carbohydrate." **18RAM** *"well in the past I had thought carb loading was a big thing, but I recently changed coach like I said before and yeah he pretty much said it is a thing but it's not as much as you think. Like, you don't have to be as extreme on the carbs."* **17CAM**	(-) Coach suggesting CHO loading not necessary	
"In the hotels I'd sort of gauge off like what the other girls are sort of eating and they, they'd eat a lot. And I'm "oh I think maybe I should eat some more instead of how much I was normally eating" and then I was just feeling bloated and heavy and.. I think I need to change this and actually work out what I need to do. But I guess it just takes time to work that all out." **19CPF** "*Because my first and the second year, you know, I'd like, you'd kind of look around and you almost adjust, and you kind of forget everything that you were, that you, you were planning to do, right, because you're just "Oh, he's doing that, I guess that's what I should do" and you kind of change you your, your way of doing things.. before I definitely used to kind of look around, And it definitely affect what you're, change what you're used to, but no, for this year, I was pretty good at that."* **37CPM** *I felt like I was eating more than the other girls. and I guess kind of commenting on, "wow, you're eating a lot" and like, "oh this is what I usually have".* **39CAF**	(~) Observing other athletes' intake and changing food intake as a result (+) No longer being distracted or influenced by what other athletes are eating (-) Observations and comments from other athletes questioning food intake when eating more	Influence of others on food intake the day before competition (18)
"with this new team that I'm on, they have a bunch of List of protocols of different nutrition things, but they have a lot of explanation for why. And some of that I was like, Oh, I didn't really know the why I just got the recommendation from an expert that I believed it was going to be is true and good. And so then just used it, like simply so yeah." **1CPF**	(+) Team providing nutrition guidelines or protocols guiding food intake (3)	Influence of the team support on food intake the day before (3)
AUTOMATIC MOTIVATION TO CARBOHYDRATE LOAD PRIOR TO COMPETITION		

"The year before, I didn't carb load but just had clif shot blocks during. And I definitely felt better carb loading. Even if I don't get my nutrition right on the bike. But when I when I didn't carb load, I did eat every, like 20 minutes and did eat enough.. but I still felt better carb loading and not eating enough." **14CAF**	(+) Experience the benefit of CHO loading on performance (6)	Factors driving motivation to practice CHO loading prior to competition (20)
"like the big pasta dinner the night before a race, that kind of thing. Just totally, like, bingeing basically on spaghetti..." **25TPF**	(-) Previously made mistakes in CHO loading intake (7)	
"*I normally try keep it just as per normal. So I don't try and change anything I'm not going to try and have a huge carb load and load up and pasta two days out. Like I'm just going to eat normally and that normally has carbs in it I guess."* ***8TPM***	(-) Aim to keep diet consistent the day before competition (14)	

Each factor categorised as having a positive (+), negative (-) or neutral (~) impact on carbohydrate loading intake during competition according to the COM-B and TDF Framework

Appendix 6. Factors influencing carbohydrate intake of endurance athletes during competition

Raw Data Quotes	**Higher order theme** **Theme/subtheme (n)**	**General dimension**
PHYSICAL CAPABILITY TO CONSUME CARBOHYDRATE DURING COMPETITION		
"Every 15 minutes I have a, my computer will beep and that is a tool that I use to keep me on a feeding schedule." **15TPF** *"I'd try and go one gel every 20 km if we're on a fast, like fast race. Cos I always go off km marks instead of time marks generally, but probably two gel's per the hour or two and a half or.. works out to be per hour."* **19CPF** "*Just once it's been hard for a bit and I look down at my Garmin, it's been, I don't know, a certain time. Oh, yeah. I don't know. Just kind of, I don't really know when I take them. I just kind of do."* **10CAF** *"And just like some races it's just like whenever you can, whenever you think about it, or whenever you get the chance really. Like, if you're following attacks and stuff, obviously you're not gonna have much time to get one in. But you know if there's ever a lull in the race, you just get one in, or yeah. Try and periodise it, not just like slam through them at once or anything."* **17CAM**	(+) Plan to eat CHO according to time (23) (+) Plan to eat CHO according to distance (3) (-) No plan - eat CHO when feel like it (4) (-) Plan to eat whenever possible during race (4)	Nutrition planning skills for competition CHO intake (44)
"Usually, I try and take everything with me in the race. Just because it's so unpredictable usually you don't know what you're going to get. But for a longer race that's like 200 K or something you can't take all of it so usually have feeders on the side of the road that will have a couple of gels or a couple of bars in the feed bag" **43CAM**	(+) Plan to use nutrition available on course or provided by team (4)	Self-reliant, carry adequate nutrition to meet needs during competition (31)

"I have used them [on course nutrition], but I do always take my own. I think the only time I have used them has been when I think I've had one or two marathons where I have felt awful and I maybe have dropped a gel and just felt like I needed something. So I would take one from the aid station, but I've always really, since I've taken it a bit more seriously, I've always taken my own gels with me, just to avoid that, that risk." **18RAM** *"I carry more than I need. Because, you know, sometimes it gets sticky, adrenaline's high, you can drop a [Clif energy] blok or two... So I would rather have more, than you know need and not have it."* **15TPF** *"I just took my gels. I took, I take all my race nutrition and training nutrition."* **47TPF**	(+) Back up plan to use on-course nutrition in case of emergency (3) (+) Carry extra CHO during race to account for any lost (15) (+) Use own nutrition products during race for control (31)	
"I would have had probably, ideally three or four [gels]. But I did I don't know I just kind of forgot and didn't like, think about it as much as I should have…No, I didn't [drink any energy drink] because I forgot, I forgot the powder. Actually I forgot lots of things in Tassie." **36CAF**	(-) Forget to bring nutrition to the competition (3)	Poor planning, forget to pack nutrition (3)
PSYCHOLOGICAL CAPABILITY TO CONSUME CARBOHYDRATE DURING COMPETITION		
"I got off like about 40 to 60 grams an hour." **2CAM** *"you can have 60 grams of carbs per hour but if you have a dual source of carbs, you can get it up to 90"* **4CAM** *"between 90 and 100 grams of carbohydrates."* **20TPF** *"we were doing, for halves [triathlon half Ironman®] like 200 to 250 calories per hour. So [for Ironman®] my coach and I decided to bump it up to 300kcal."* **5TPF**	(+) Aim for 40 - 60g CHO per hour (4) (+) Aim for 60 - 90g CHO per hour during competition (8) (+) Aim to consume 90-120g CHO per hour (2) (+) Aim to consume 200-350kcal per hour (6)	Knowledge of how much CHO to consume during competition (29)

"*aim for 1g of carbohydrate per kg of body weight per hour or something like that*" **17CAM** *"on the run you want to be trying to take sort of maybe like three to four gels an hour. I think I usually end up taking two to three depending on like the race and how I'm feeling"* **42TAF** *"I don't necessarily know like the grams per, like, grams per kilogram and specific amounts and stuff, but I know roughly what I should be consuming and how much of it."* **43CAM**	(+) Aim for 1g.kg per hour (1) (+) Aim for 2-4 gels per hour (10) (-) Unsure how much CHO to consume per hour during competition (15)	
"*I just like stick with what I know, it's also just, I'd rather just take what I have and be self-sufficient. Like it just slows you down on the bike to have to take stuff of other people. So I just, yeah stick to what I know, make sure I can take on what I want to be self-sufficient for the duration of the race.*" **31TAF** *"I practice with that [race nutrition] in training. So if I have like a really heavy training day, I will aim for that. So I'm kind of used to it*" **15TPF**	(+) Self-reliant, Use known foods and nutrition products during competition (14) (+) Tested nutrition in training (28)	Confidence in nutrition plan during competition (26)
"I usually I kind of skimp on a bar here and there during the bike.. I'm resistant to taking a gel as early in the run as I think it should so I'm like "no, I'm not hungry. I won't, I don't need it yet".. I'm always afraid of it though. I am always, I almost always under do it rather than overdo it because I'm so worried about having stomach issues.. I'll sooner not eat than risk a stomach issue. Which is weird because I haven't had stomach issues. I avoid that at all costs. Sometimes to the detriment of my performance." **25TPF** "*I only ended up getting through half the gel, it tasted awful. Gave up on it."* **40TAM**	(-) Intentionally limit energy intake to minimise gut distress (1) (-) Intentionally choose not to consume CHO due to taste (1)	Intentionally choose not to eat CHO during competition (2)
"the weather definitely. Because if it's hot like this, you drink automatically because you need it, you feel that you need it. So you need to make the sports drinks more, less concentrated. But I get more fluid in together with the energy" **20TPF**	(~) Hot weather influencing intake (28)	Weather impact intake during competition (n=37)

SOCIAL OPPORTUNITY TO CONSUME CARBOHYDRATE DURING COMPETITION		
"your diet is kind of influenced... I think there's like something that kind of goes on.. when you're around other people and their dietary habits you tend to like, well I tend to pick them up." **2CAM**	(~) Influence of other athletes on food intake during competition (n=2)	Influence of others on food intake during competition (29)
"for this race specifically, the Australian team sends us nutrition guidelines and really emphasises carbohydrate loading not just the day before the race, but actually the week before the race. And they really emphasise exactly what how much nutrition you should have during the race, they tell you the information about what the products are and stuff." **7CPF**	(+) Influence of team on food intake during competition (n=2)	
"I worked with a nutritionist, and then kind of experimented with my races before that one. So I had done the World Championship 70.3 in Nice. And that worked out, like my nutrition was perfect that day, and you had a really great, great experience of that race. So I just kind of expanded it for the full." **6TPF**	(+) Influence of sports nutritionist or dietitian on food intake during competition (n=14)	
I definitely under ate. The first day I had two gels, my coach told me to have two gels an hour. I can't remember exactly how many I had, I think was like three or four **32CAF**	(+) Influence of coach on food intake consumed during competition (n=18)	
REFLECTIVE MOTIVATION TO CONSUME CARBOHYDRATE DURING COMPETITION		
"The very first place I know that I noticed if something's off nutritionally, is my head, meaning clarity of thought. I will go fuzzy.. That's usually an indication that my carbohydrates are low" **15TPF**	(+) Impaired mindset and loss of concentration during competition prompting CHO intake (n=8)	Reflective motivation influencing CHO intake during competition (38)
"I start getting... some cramps and just you know, general like fatigue, You just feel it, just the race is so hard too like at some point. It's going to slow down eventually. But it's just like, more [fatigue] so when I don't eat enough. " **37CPM**	(+) Experience physical fatigue during competition prompting CHO intake (n=20)	
I almost always under do it rather than overdo it because I'm so worried about having stomach issues." **25TPF**	(-) Fear of experiencing gut issues during competition influencing CHO intake (n=38)	
AUTOMATIC MOTIVATION TO CONSUME CARBOHYDRATE DURING COMPETITION		

I've had marathons in the past where I've got to sort of 20, 21 miles and felt like I was running out of energy and my legs have got really heavy and that sort of things, but it didn't really happen this time around. So I'm sure part of that must have been better nutrition and yeah, definitely I still felt strong coming in to the last sort of five, six kilometres" **18RAM**	(+) Experience benefit in performance when consume CHO during competition (n=13)	Motivation to increase CHO intake during competition (n=30)
"When I first started racing, the first ever Half Ironman® I did, I didn't take any nutrition on for the last hour and a half of the race. I just felt like I didn't need it and I'd never done a half before… I started sprinting on the finishing line because everyone was saying she [girl in first place] was so close and I fell over and face planted twice, you know, like you can get the wobbles? I face planted twice in the finishing shoot and she came past and beat me. So from that day onwards, I've kind of acknowledged the importance of nutrition in my racing and I think I'm pretty consistent." **13TPF**	(+) Learn from experience from previously under consuming CHO during competition (n=25)	

Each factor categorised as having a positive (+), negative (-) or neutral (~) impact on carbohydrate intake during competition according to the COM-B and TDF Framework