Ultra-endurance athletes' food choices, nutrition knowledge and strategies to improve dietary intake and performance

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Declaration

I certify that I am the author of the thesis entitled ‘Ultra-endurance athlete’s food choices, nutrition knowledge and strategies to improve dietary intake and performance’ submitted for the degree of Doctor of Philosophy.

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Abstract

Introduction: Participation in ultra-endurance events has increased exponentially in recent years. Despite this, performance in such demanding events has been stagnant. Numerous studies have observed that ultra-endurance athletes consistently fail to meet the extensive energy demands and the current carbohydrate (CHO) recommendations, which may in part explain this plateau in performance. To date, little is known about the causes of suboptimal energy and CHO intake or the most effective strategies to address these inadequacies. Therefore, the aims of this thesis were to (i) explore the challenges to optimal nutritional intake, (ii) establish whether a gut-training programme could enable ultra-endurance athletes to meet the CHO recommendations and (iii) determine whether a short term high fat, low CHO diet (HFLC) or a low fat, high CHO (LFHC) diet prior to competition is more effective for ultra-endurance performance, when fuel availability is likely to be compromised.

Methods: One hundred and seventy participants took part in the studies involved in this thesis, including 118 ultra-endurance athletes. The remaining participants consisted of three population groups with different levels of nutrition knowledge and experienced distance athletes, who were involved in the developmental phase of the first two studies. Both studies employed a two-phase approach to (i) adapt and evaluate a questionnaire for use with ultra-endurance athletes; and (ii) subsequently implement the questionnaire with these athletes (*n* = 101). The first questionnaire was completed alongside a series of 24 hr food diaries to explore the relationship between nutrition knowledge and food intake. The second explored the main factors that influence food choices during training and competition. The penultimate study required ultra-runners (*n* = 17) to follow a multicomponent dietary intervention (gut training + HFLC compared with gut training + LFHC diet), which was designed to overcome identified challenges to optimal nutritional intake and to optimise fuel availability in preparation for a 56 km ultra-endurance foot race. The final study explored the experiences of a subsample of ultra-endurance runners (n = 14) as they made their food choices during the race, using a series of face-to-face interviews.

Results and discussion: The nutrition knowledge of ultra-endurance athletes was superior to the general population, however there was no relationship between knowledge and the adequacy of the ultra-endurance athletes diet. The most important factors that influenced the food choices of these ultra-endurance athletes were the avoidance of gastrointestinal symptoms (GIS) and the provision of adequate energy. These factors were followed closely by the desire for nutritious products and those that were easy to consume during training and competition. The multicomponent intervention successfully manipulated the CHO and fat composition of the 17 ultra-endurance athletes, however this did not affect their race performance. Furthermore, despite a period of gut training designed to improve the ultra-runners tolerance of high volumes of CHO, ultra-runners failed to meet the recommended rate of CHO intake and the severity of their GIS did not improve. Subsequent analysis of the interviews indicated that the processes involved in making food choices during the race were complex and dynamic. All ultra-runners altered their food choices during the race in response to triggers, such as hunger and taste fatigue. This resulted in the consumption of lower CHO density products, which may partially explain the suboptimal CHO intake.

Conclusion: Advances in ultra-endurance performance appear to be restricted in part by the adequacy of the athlete’s nutritional intake. At present, strategies to address the multiple challenges to optimal nutritional intake have had limited success. However, practicing competition nutrition during training is likely to simplify the decision-making process during events, allowing ultra-endurance athletes to focus on their performance.

Key words: ultra-endurance, nutrition, knowledge, food choice, fat, carbohydrate.

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Contents

List of Figures

List of Tables

List of Abbreviations

%HR$_{max}$	Relative heart rate max
ANOVA	Analysis of variance
AT	Anaerobic Threshold
BF	Body fat percentage
BM	Body mass
BMI	Body mass index
CHO	Carbohydrate
CI	Confidence interval
COMP	24 hr containing an ultra-endurance competition
C$_m$	Oxygen cost of motion
C$_r$	Oxygen cost of running
EAH	Exercise associated hyponatraemia
EoM	Economy of movement
FM	Fat mass
GE	Gastric emptying
GenP	General population
GI	Gastrointestinal
GIS	Gastrointestinal symptoms
GNB	Gram negative bacteria

GPS	Global positioning system
GT	Gut training
HFLC	High fat, low carbohydrate diet
HR	Heart rate
HR_{cycle}	Heart rate during cycling
HR_{swim}	Heart rate during swimming
$HRVT_1$	Heart rate at aerobic ventilation point
$HRVT_2$	Heart rate at anaerobic ventilation point
IL-6	Interleukin -6
I-FABP	Intestinal fatty acid binding protein
Kcals	Kilocalories
LFHC	Low fat, high carbohydrate diet
LPS	Lipopolysaccharide
MANOVA	Multivariate analysis of variance
MD	Mean difference
METS	Metabolic equivalents
NM	Neuromuscular
OCTT	Oro-cecal transit time
Pre-COMP	24 hr before an ultra-endurance competition
Pre-TRAIN	24 hr before an ultra-endurance training session

RCP Respiratory compensation point

RD Registered Dietitian

RER Respiratory exchange ratio

RPE Rating of perceived exertion

SENr Sports and Exercise Nutrition Register

TRAIN 24 hr containing an ultra-endurance training session

TRIMP Training impulse

ULTRA-FCQ Food choices questionnaire adapted for ultra-endurance athletes

ULTRA-Q Sports nutrition knowledge questionnaire adapted for ultra-endurance athletes

$\mathbf{V_{\wedge 1mmol}}$ Lactate threshold: increase of 1 $mmol.l^{-1}$

$\mathbf{V_{2mmol}}$ Lactate threshold: at 2 $mmol.l^{-1}$

$\mathbf{V_{4mmol}}$ Lactate threshold: at 4 $mmol.l^{-1}$

$\mathbf{V_{e}}$ Ventilation

$\mathbf{VO_2}$ Volume of oxygen

$\mathbf{VO_{2max}}$ Maximum oxygen uptake

$\mathbf{VO_{2peak}}$ Peak oxygen consumption

List of Appendices

Chapter 1: Introduction

1.1 Introduction

Nutrition is integral to athletic performance for a number of key reasons. Firstly, in the preparation phase: nutrition is instrumental to optimise training adaptations (Hawley & Burke, 2010), and for achieving desirable body composition for economy of movement and thermoregulation (Thomas, Erdman, & Burke, 2016). In the performance phase: nutrition is vital for optimising fuel stores (particularly muscle glycogen) and hydration status for performance during competition and important training sessions (Burke, Hawley, Wong, & Jeukendrup, 2011). In ultra-endurance sport, the importance of nutrition to athletic performance is likely to be heightened given the limited storage of muscle glycogen (Burke et al., 2011). Although, interpretation of the role of nutrition in ultra-endurance performance needs to be with the context of the scale of these competitive activities (Section 1.2), the participation trends (Section 1.3) and performance trends (Section 1.4).

1.2 Classification of Ultra-Endurance Competition Activities

In the domain of ultra-endurance nutrition there is some conflict about the threshold distance or time for an activity to be deemed ultra-endurance. Some authors have chosen a standard definition based on distance, with anything above 42.2 km (traditional marathon) constituting an ultra-marathon (Knechtle, Valeri, Zingg, Rosemann, & Rüst, 2014). Specific events above the traditional marathon distance (i.e. 50 km, 100 km, 24 hr) have been officially recognised, with championship competitions held annually (International Association of Ultrarunners, 2017). An ultra-endurance triathlon has been defined as anything greater than the Ironman distance (Knechtle, Knechtle, & Lepers, 2011). Using these two definitions, running events such as Stort 30 (30 mile / 48 km) and Dark Star River (28 mile / 44.8 km), along with the Double, Triple and Decca Ironman triathlons would be catergorsied as ultra-endurance events. The best performance times for the aforementioned running events during 2016 were ~3 hr 16 min, whereas the world best performance time for the double Ironman triathlon was more than six times longer (19 hr 54 min). The vast differences in performance times for events classified in this way are somewhat misleading and therefore alternative definitions based on time are often favoured.

Peters, (2003) employed a minimum duration of 4 hr for top performers, which based on the winning performances from 2016 would include Ironman 70.3 Staffordshire (4 hr 01 min), Northants Ultra 35 mile (4 hr 12 min), St Peters Way 45 mile (5 hr 40 min) and Thames Trot Ultra 50 mile (5 hr 49 min). In contrast, to avoid confusion with the traditional marathon (42.5 km), which is completed on average in 4 hrs, Zaryski and Smith (2005) proposed a minimum duration of 6 hr for events to be classified as ultra-endurance. Events greater than 6 hr for top performers (according to 2016 results) would include the standard Ironman triathlon, along with the running events Nomad Ultra 50 mile and the Apocalypse 50 mile. This definition would discount events such as the Thames Trot Ultra despite its comparable distance (50 mile), which is almost double the traditional marathon. As such, in the absence of a consensus, the definition used throughout this thesis is 'a minimum of 4 hrs for top performers' as recommended by Peters (2003). This was favoured over the set distance definition as it is difficult to standardise distance across the full range of ultra-endurance disciplines (e.g. ultra-running compared to ultra-triathlon).

Further complicating nutrition research in this sporting discipline is the range of race structures, which mean the athletes may be exposed to a variety of stressors and challenges to optimal nutrition. Firstly, the single day event that can last up to 24 hr typically results in very high energy expenditures (15533 kcal) that are difficult if not impossible to meet (Bescós et al., 2012). This is likely to be especially challenging for the longest events, as athletes will inevitably complete part of the race in darkness. Athletes may focus more on the terrain and staying safe as they run or cycle by flashlight. Secondly, the multi-stage event that consists of several consecutive days of ultra-endurance activity. These events require athletes to cover set distances each day usually within a specific cut off time for each stage. The Marathon des Sables has a maximum time allowance of 10 hrs per day. As such, the athlete's nutritional strategy needs to consider several aspects of nutrition: (i) fuel for each stage, (ii) nutrition to promote recovery and (iii) strategies to replenish fuel for the next stage.

Finally, there are semi-continuous ultra-endurance events that take place over several days as one continuous stage, again restricted by a maximum race time. In these events, athletes typically stop for as little time as possible over the course to ensure they meet the strict cut off time. As such, sleep deprivation is common, with athletes often sleeping for <2.4 hr per day (Lahart et al., 2013). This also has the potential to impair the athlete's nutritional intake, with athletes minimising stops to consume food and fluids. As the range of ultra-endurance events are likely to have considerable different implications for nutritional requirements and nutritional intake, this thesis focuses on single day events, in an attempt to minimise the potential confounding effect of sleep deprivation and inadequate recovery between stages.

1.3 Ultra-endurance Participation Trends

Participation in ultra-endurance events has seen a marked increase over the last 20+ years. In both fixed distance and fixed time ultra-endurance marathons, participation trends indicate that the number of finishers has increased annually from 1975 to 2013 for both males and females (Gerosa, Rüst, Rosemann, & Knechtle, 2014;

Knechtle et al., 2014; Lenher, Knechtle, Rust, Rosemann, & Lepers 2012; and Sehovic, Knechtle, Rüst, & Rosemann, 2013). Worldwide data indicate that for ultra-endurance marathons lasting 6 hr and those covering the 161 km distance, there have been sharp increases in participation at specific time points. As an example, participation increased considerably in 2005 for the 6 hr races (Ehrensperger, Knechtle, Rüst, & Rosemann, 2013), whereas the 161 km distance saw three separate periods of significant increases, first in 2002 (25.1%), then 2007 (16.8 %) and 2009 (27.9%) (Gerosa et al., 2014). The reasons for these marked increases are currently unknown, however, interest in these events has been attributed to a greater appeal for trail races compared to road races (Hoffman, Ong, & Wang, 2010) and self-fulfilment (Gerosa et al., 2014). The largest participation rates in time limited foot races were seen in the 6 hr and 24 hr events, with approximately 6000 male athletes completing these events in 2013 (Knechtle et al., 2014). Although, this is considerably lower than the 50000 triathletes competing in half and full Ironman distance triathletes each year (Stiefel, Rüst, Rosemann, & Knechtle, 2013).

Participation rates in ultra-endurance events appear to vary by geographic location, age and gender. North America has the largest participation rates for 161 km foot races (Gerosa et al., 2014) and Ironman distance triathlons (Stiefel et al., 2013), whereas Europeans account for the majority of 100 km finishers (Cejka et al., 2014). This likely reflects the distribution of races around the world, as the majority of competitors tend to compete in their home nations and continents (Ehrensperger et al., 2013; Gerosa et al., 2014). Indeed, athletes travelling outside of their home continent accounted for <2% of participants in 6 hr ultra-marathons (Ehrensperger et al., 2013). The greatest increase in participation appears to be in athletes of middle age for time restricted ultra-marathons (Ehrensperger et al., 2013) and Ironman distance triathlons (Stiefel et al., 2013). In relation to gender, a considerably lower rate of female participation compared to males has been observed in ultra-marathons of varying distances and time limits, accounting for 15.3% to 21.0% of participants (Cejka et al., 2014; Gerosa et al., 2014; Knechtle et al., 2014). Similarly, the percentage of female finishers in the Ironman qualifiers and Ironman championship account for just 18.9% and 27.2% of all finishers respectively (Stiefel et al., 2013).

Together, these participation trends indicate that athletes are increasingly taking part in events of extreme distances and durations, which are accompanied by considerable challenges to energy availability and hydration status. Similarly, the training volumes typically required for such prolonged events require appropriate fluid and energy replacement strategies to enable ultra-endurance athletes to cope with the heavy training demands (Zaryski & Smith, 2005). Furthermore, the greater participation rate of athletes aged 30-64 yr suggests that the majority of ultra-endurance athletes are recreational. Therefore, they likely balance training and competing around their working and family commitments. As such, their nutritional intake may be influenced by social and environmental factors outside of the sporting domain in which they compete.

1.4 Ultra-endurance Performance Trends and the Role of Nutrition

The increase in ultra-endurance participation has in turn led to an interest in performance trends for such events. Studies that have explored performance data in ultra-endurance races have generally focused on events with the greatest number of participants i.e. >500 participants (Cejka et al., 2014; Ehrensperger et al., 2013). Available data from countries with the highest participation rates for the 100 km distance ultra-marathon (1998 to 2011) indicate that with the exception of a select group of countries, performance times have remained relatively stable (Cejka et al., 2014). A similar trend for stable performance times was also observed for both males and females in Ironman distance triathlons, albeit after an initial decrease from 1981 to 1988 (Lepers, 2008). However, in general, race times for females have been consistently slower than males during ultra-endurance marathons (Cejka et al., 2014; Ehrensperger et al., 2013) and ≥Ironman distance triathlons (Lepers, 2008; Rüst, Knechtle, Knechtle, Rosemann, & Lepers, 2012). In the latter, the performance gap appears to be greatest for the deca Ironman (Rüst et al., 2012).

The stability of performance times for males and females may reflect the motives for taking part in ultra-endurance events. The Motivation of Marathoners Scale indicated that ultra-marathon runners were motivated by personal achievement rather than competition (Hanson, Madaras, Dicke, & Buckworth, 2015), suggesting that performance was not as important to ultra-endurance athletes. Ironman distance triathletes cited similar intrinsic motives, with individuals wanting to test the physical limits of their bodies and experience the euphoria of completing such challenging events (Lamont & Kennelly, 2012). Alternatively, it is highly likely that the stability of ultra-endurance performance also reflects the paucity of controlled trials in order to provide an evidence base for nutrition recommendations for optimum performance. There is considerable evidence that endurance performance (>1 hr) is improved by the ingestion of fluid and carbohydrate (CHO), however, there is very little empirical research exploring optimal nutritional strategies for activities >4 hrs (Burke et al., 2011). Consequently, athletes and the professionals supporting them rely on scientific evidence from endurance sports typically lasting <3 hr (Knechtle, 2013), which do not replicate the demands of ultra-endurance activities.

Nutritional factors limiting performance in endurance sport often centre on CHO depletion (Thomas, Erdman, & Burke, 2016) and dehydration (body mass >2% or body water ~3%), especially in warm conditions (Sawka et al., 2007), while for events lasting >4 hr additional factors have been proposed. These include exercise-associated hyponatremia (EAH), characterised by blood sodium concentration <135 $mmol.l^{-1}$ and exercise induced gastrointestinal (GI) distress (Jeukendrup, 2011). Numerous observational studies have indicated that energy deficits and suboptimal rates of CHO intake during ultra-endurance competition are prevalent (Black, Skidmore, & Brown, 2012; Kimber, Ross, Mason, & Speedy, 2002; Kruseman, Bucher, Bovard, Kayser, & Bovier, 2005). As such, glycogen depletion is a probable cause of fatigue in ultra-endurance athletes as well as endurance athletes. Although, interest has been reignited into the utility of dietary manipulation for sparing glycogen and increasing fat oxidation as an alternative fuel source for prolonged events (Burke, 2015). Strategies such as short-term high fat, low CHO diets (HFLC) have resulted in adaptations that increase fat oxidation (Carey et al., 2001). However, it is unclear at this time whether this translates into performance benefits for ultra-endurance competition. To date, limited data exists on the effectiveness of nutritional strategies optimising fuel availability for ultra-endurance performance. Nonetheless, given the limited glycogen storage capacity, a multicomponent dietary intervention is likely to be required to delay fatigue and subsequently improve performance. Therefore, research should assess the effectiveness of combining strategies to optimise glycogen storage prior to competition with those that increase fuel availability during said events, in an attempt to enhance performance.

The volume and composition of fluid required by ultra-endurance athletes and the impact on performance is equally complex. This is partially due to the variable needs associated with the extreme environmental conditions athletes may be exposed to, and the intra-individual variability in sweat-rates (Sawka et al., 2007). As an example, during ultra-running events, fluid intake ranging from 520 ± 180 $ml.hr^{-1}$ (Knechtle et al., 2010) to 732 ± 183 $ml.hr^{-1}$ (Costa et al., 2013) have been shown to limit dehydration during temperate and hot climates, respectively. This was evident with <3% loss of body mass (BM), which was accompanied in the latter study by plasma osmolality within the normal clinical range (280 to 303 $mOsmol.kg^{-1}$).

During endurance activities completed under similar environmental temperatures, considerable reductions in performance (8-29%) have been observed with BM losses of between 2% and 4% (Sawka, Chevront & Kenefick, 2015). In contrast, Hoffman and Stuempfle (2014) failed to identify a relationship between performance and hydration status using the percentage of BM loss as their main marker of hydration. Change in BM alone is not a sensitive marker of hydration status for ultra-endurance events as weight loss can partly be attributed to glycogen depletion and urine output (Rehrer, 2001), along with decreases in skeletal muscle mass and fat mass (Knechtle, Wirth, Knechtle, & Rosemann, 2009). Furthermore, weight gain during ultra-endurance can occur due to peripheral oedema (Bracher et al., 2012), adding to the complexity of this field of study. The difficulties in adjusting for these confounding factors and obtaining biochemical markers of hydration during race conditions has negated a clear picture of the influence of hydration status on ultra-endurance performance.

Furthermore, sodium consumption of 270 ± 151 $mg.l^{-1}$ (Costa et al., 2013) and 425 ± 478 $mg.hr^{-1}$ (equating to ~817.3 $mg.l^{-1}$) during ultra-marathons (Knechtle et al., 2010), has been adequate to prevent EAH for some but not all athletes. The lower sodium concentration of fluids recorded by Costa et al., (2013) resulted in hyponatremic blood sodium concentration (i.e. <135 mmol.l^{-1}) for 42% of the ultra-runners. Suggesting higher concentrations of sodium are required for a large proportion of athletes. In an earlier study, EAH was present in just five out of 123 ultra-runners when the temperature was modest (8 to 14^{o}C) (Page, Reid, Speedy, Mulligan, & Thompson, 2007). The presence of EAH in their study was associated with an average weight gain of 1.32 kg (1.5 to 1.6 kg), indicating that excessive fluid intakes may have had a dilution effect on blood plasma concentration. However, EAH has been reported with weight gain (23.8%), weight loss (35.6%) and weight stability (40.6%) alike, in a group of ultra-runners during a 161 km race (Hoffman, Hew-Butler, & Stuempfle, 2013) suggesting an element of interindividual variability.

The impact of EAH on performance also appears to be variable, as three out of five hyponatreamic runners observed by Page et al., (2007) were able to complete their ultra-running race faster than the average race time, however, in extreme cases EAH can be fatal (Hew-Butler, Loi, Pani, & Rosner, 2017). Together this suggests that for ultra-endurance athletes there is a delicate balance between fluid and sodium consumption and both the hydration status of the athletes and their risks of hyponatreamia. Management of hydration status is therefore likely to be important to overall ultra-endurance performance.

Finally, in single and multi-stage ultra-marathon races, gastrointestinal symptoms (GIS) have been reported to impair performance for approximately one third of runners (Costa, Snipe, Camões-Costa, Scheer, & Murray, 2016; Hoffman & Fogard, 2011). This has resulted in significantly slower race times ($p = 0.008$) and difficulty making cut-off times ($p = 0.008$) for those experiencing nausea (Hoffman & Fogard, 2011). Although, the actual race times of those experiencing symptoms were not reported. Furthermore, GIS can be the main cause of ultra-endurance athletes dropping out of a race (Glace, Murphy, & McHugh, 2002; Hoffman & Fogard, 2011; Stuempfle & Hoffman, 2015), with 23% of runners who failed to complete a 161 km foot race citing nausea/vomiting as the main reason (Hoffman and Fogard, 2011). In contrast, mild nausea was offset by the high CHO intake of Ironman triathletes, suggesting performance may not be impaired by the presence of this particular GIS (Pfeiffer et al., 2012). While some ultra-endurance athletes have been able to maintain performance or at least complete the race despite GIS, the potential for symptoms to limit performance is widespread due to the high prevalence in ultra-endurance athletes.

Gastrointestinal symptoms have been observed in up to 93% of ultra-endurance triathletes (Jeukendrup, Vet-Joop, Sturk, Stegen, Senden, Saris, & Wagenmakers, 1999) and 96% ultra-endurance runners (Stuempfle & Hoffman, 2015). Furthermore, Ter Steege and Kolkman (2012) reported that in general GIS have been more prevalent in females, which could in part explain some of the performance differences between males and females. The prevalence and severity of GIS has been exacerbated by dehydration (Van Nieuwenhoven, Vriens, Brummer, & Brouns, 2000) and the consumption of specific types of carbohydrate (Sessions et al., 2016), providing evidence of an interaction between nutrition and GIS. This interaction appears to be bidirectional as the presence of GIS has been proposed to impair nutritional intake (Costa et al., 2016). As such, future studies are likley to benefit from combining strategies to enhance fuel availability with those that prevent GIS.

In summary, it is highly likely that glycogen depletion, dehydration, exercise associated hyponatraemia and GIS, which are common during ultra-endurance training and competition, contribute to the stagnancy of performance in this population group. These factors are further exacerbated by extreme environmental conditions and they are likely influenced by the technical difficulty, or the logistical challenges and physical demands associated with the landscape (Williamson, 2016), which can include remote mountainous terrains or in extreme cases high altitude and sub-zero temperatures accompanied by routes covered in thick snow (Mariah Media Network, 2017). In the UK, the majority of races are likely to be less demanding given that the average temperature recorded during 2016 was 9.3 ^{o}C (Met Office, 2017) and the highest altitude measures just 1344 m (The Mountain Guide, 2017). As such, this thesis will focus on short-term nutritional strategies that can be implemented during training and in preparation for single day ultra-endurance events, which take place in temperate environmental conditions comparable to the UK.

Chapter 2: Review of the literature

2.1 Introduction to the Literature Review

This chapter presents a broad review of the literature that underpins the studies included in Chapters 3 to 5. It begins with a concise review of key physiological factors proposed to be associated with successful performance during ultra-endurance competition. The review continues with a discussion of the role of nutrition in optimum performance. This is followed by a review of current nutritional recommendations for ultra-endurance performance in comparison to the nutritional intake of ultra-endurance athletes; focussing on acute fuelling strategies for before and during prolonged training and competition, in order to maximise fuel availability. This chapter concludes with a review of the main challenges to optimum nutritional intake during competition; including the level of nutrition knowledge, and motives for ultra-endurance athletes' food choices and GIS.

2.2 Factors Associated with Successful Ultra-Endurance Performance

Unlike shorter endurance races that predominantly measure performance based on time to complete a set distance, ultra-endurance races comprise both performance time for a fixed distance and total distance covered during a set time, typically 6, twelve and twenty-four hours. Despite this, research appears to focus mainly on the traditional measures of performance (i.e. time to complete a set distance) and may not be transferable to time-limited events. Nonetheless, Millet, Hoffman, and Morin (2012b) have attempted to present an overview of the factors that influence ultra-endurance performance (Figure 2.1), albeit in relation to running alone.

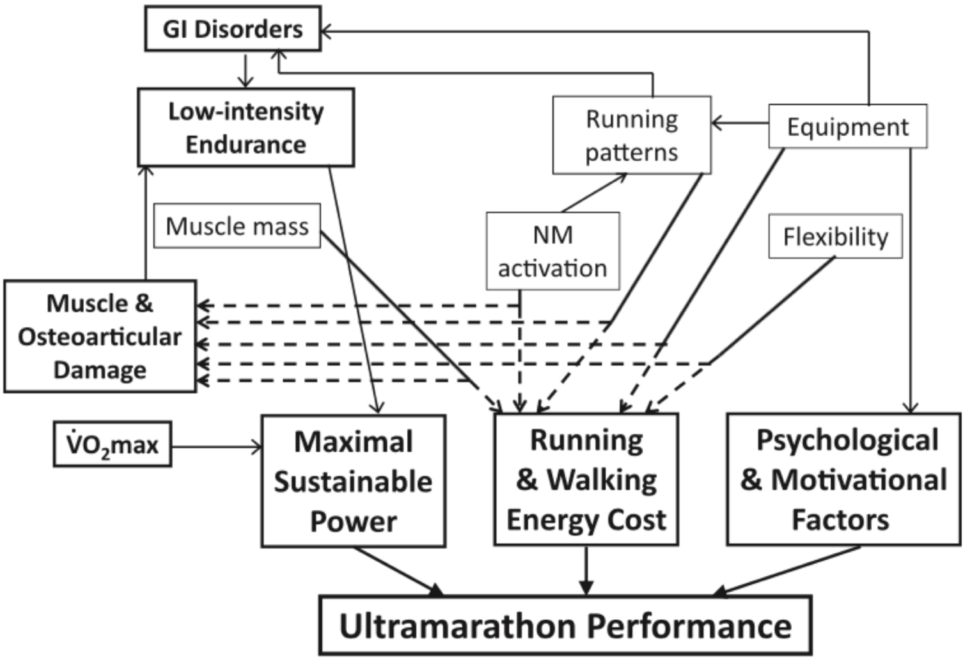


Figure 2.1. Proposed variables that contribute to ultra-endurance running performance (Millet et al., 2012b, p. 507) (NM = neuromuscular, GI = gastrointestinal). Factors considered as most important appear in bold and those that represent compromise between energy cost and lower limb tissue injury are indicated by dashed lines.

Starting with the factors in closest proximity to ultramarathon performance, the schematic (Figure 2.1), emphasises the importance of the variables; maximal sustainable power and energy cost of running (running economy), along with psychological and motivational factors. Furthermore, it illustrates that maximal sustainable power is in part dependent on the maximal oxygen consumption (VO_{2max}) of the athlete. The importance of this physiological variable for endurance performance has been established since the early 20th century (Hill, Long & Lupton, 1924), however understanding of its limiting factors has evolved considerably since then (Saltin & Strange, 1992). While there is evidence of a genetic predisposition to high aerobic capacity, with appropriate stimulus, endurance training produces adaptations to the systems involved in oxygen delivery and extraction, resulting in improvements in VO_{2max} (Lundby, Montero, & Joyner, 2017). The principles underpinning these adaptations are effectively summerised by Levine, (2008).

It may be anticipated that the importance of a high VO_{2max} may be less pronounced for ultra-endurance activities, given the relatively low intensity (39% of, VO_{2max}) maintained throughout a 24 hr treadmill ultra-marathon (Gimenez, Kerhervé, Messonnier, Féasson, & Millet, 2013), compared to a standard marathon (76% of VO_{2max}) completed on a treadmill (Bosch, Goslin, Noakes, & Dennis, 1990). Despite this, evidence suggests that maximal oxygen consumption is an important component of ultra-endurance performance. This is evident, as both single and multiple modality events have documented strong associations between VO_{2max} and performance (Barrero, Chaverri, Erola, Iglesias, & Rodríguez, 2014; Fornasiero et al., 2017; Millet et al., 2011). Most recently, Fornasiero et al., (2017) observed a strong, negative correlation between performance time and VO_{2max} (r = -0.66, p <0.001) during a 65 km mountain ultra-marathon. Although, it is noteworthy that multiple regression analysis indicated that VO_{2max} combined with key anthropometric parameters (body mass index and percentage body fat) explained just 59% of the variability in performance between these athletes. Indicating that VO_{2max} alone was not capable of predicting ultra-endurance performance.

Similarly, Barrero et al., (2014) observed that VO_{2max} combined with the difference in heart rate (HR) between the cycle and swim components of an ultra-endurance triathlon, explained 81% of the variability in performance. Thereby reinforcing the notion that both VO_{2max} and the ability to maintain exercise intensity are key factors to ultra-endurance performance (Millet, et al., 2012a). Resistance to fatigue appears to be a more dominant influence on performance in the latter stages of such events, as the correlation between maximum oxygen consumption (VO_{2peak}) and performance were present during the cycling (r = 0.86, p <0.001), but not the running component of an Ironman distance triathlon (Marongiu et al., 2013). The absence of a relationship between aerobic capacity and performance during the running element of the Ironman distance triathlon, suggests that the dominance of this variable on performance diminishes as the duration of the event increases. Given that even the fastest triathletes, commence the run segment, after >5 hr of endurance activity (World Trialthlon Corporation, 2017), it is likely that glycogen depletion, and dehydration may have mitigated the performance benefit, associated with a high VO_{2max}. As such, the original schematic representation of factors influencing ultra-endurance performance has been revised to reflect the importance of nutrition for maintaining exercise intensity (Figure 2.2).

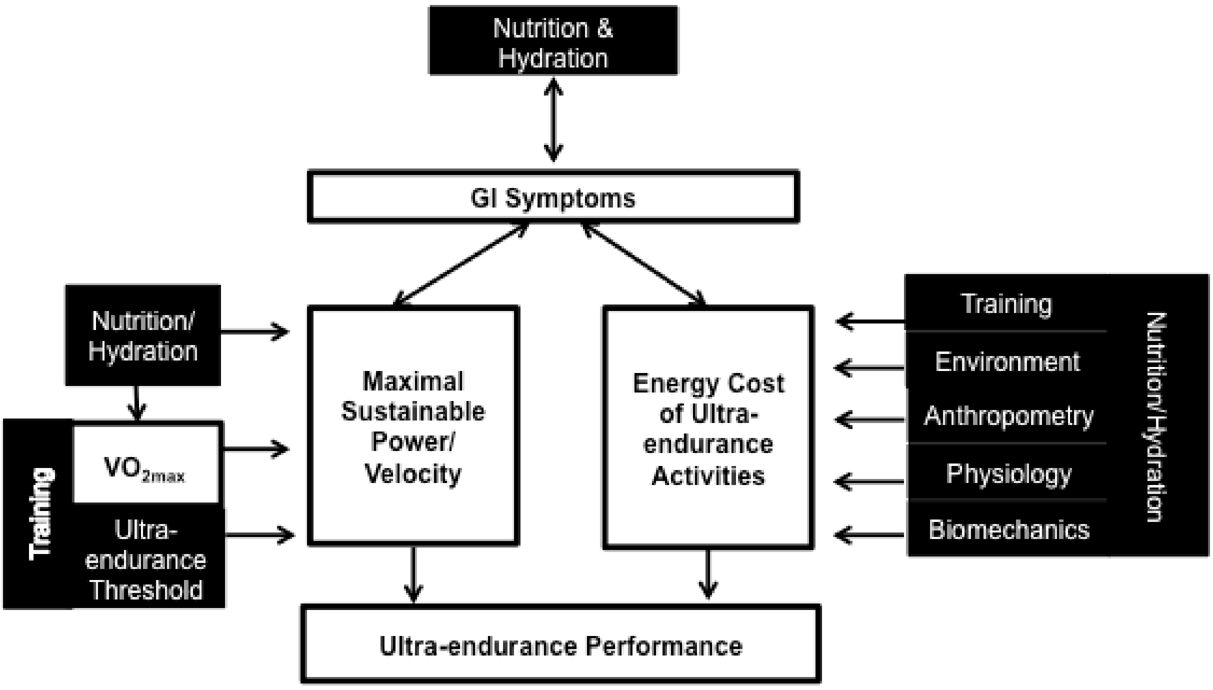


Figure 2.2. Proposed revision to the schematic representation of factors that influence ultra-endurance performance. Key physiological factors (maximum sustainable power and energy cost of ultra-endurance activities) are influenced by training, athlete characteristics and the event conditions. These can be modulated by nutrition and hydration, along with GIS. Furthermore, GIS can have a negative impact on nutritional intake, with potential consequences for performance.

Millet and colleagues (2012b) postulated that lactate threshold is less influential to ultramarathon performance in comparison to shorter events; therefore it was not represented in their schematic. At first glance, this is not overly surprising, given that ultra-endurance athletes typically compete at intensities (<65% VO_{2max}) below ventilation (Barrero et al., 2014; Laursen, et al., 2005) and lactate thresholds (Millet, at al., 2011). Furthermore, Millet's earlier work failed to establish an association between specific lactate markers (to 2 $mmol.l^{-1}$, 4 $mmol.l^{-1}$ or an increase in lactate of 1 $mmol.l^{-1}$ above resting) and performance, during a 24 hr treadmill protocol (Millet et al., 2011). However this interpretation of the relationship between lactate threshold and ultra-endurance performance is simplistic and fails to acknowledge the interaction between key physiological variables that contribute to optimum endurance performance.

Joyner and Coyle (2008) captured this interaction effectively, illustrating how both aerobic and anaerobic capacity, along with 'efficiency' of exercise, often referred to as economy of movement (EoM) or energy cost of exercise, contribute to performance velocity during endurance activities (Figure 2.3). The weighting of these individual variables, to ultra-endurance performance, likely reflects the event characteristics. Specifically, lactate threshold is likely to have a greater contribution when ultra-endurance events are marginally longer than traditional marathon races. Especially, given that a strong correlation has been observed between marathon performance and both fixed lactate and variable lactate thresholds (Faude, Kindermann & Meyer, 2009). Similarly, an ultra-endurance athlete's performance during events that include mountainous climbs is likely to be compromised by limitations in buffering capacity. In place of established lactate and ventilation thresholds, Laursen & Rhodes, (2001) have suggested that ultra-endurance performance for longer less intense events may be characterised by intensity slightly below the anaerobic threshold (AT), which they have termed ‘ultra-endurance threshold’. As such, the schematic developed by Millet, and colleagues (2012b) has been further refined to acknowledge the contribution of this new physiological threshold (Figure 2.2).

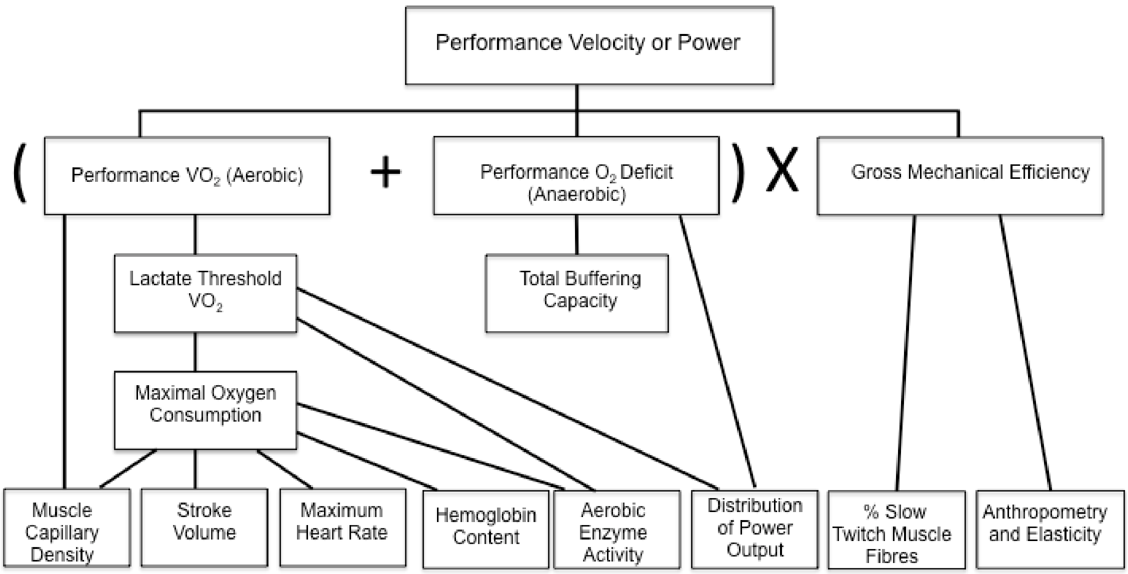


Figure 2.3. Schematic representation of the physiological factors that influence endurance performance (Joyner & Coyle, 2008, p. 37).

Despite a paucity of research exploring the contribution of energy cost/EoM, to ultra-endurance performance, Millet and colleagues (2012b) appear to give similar weighting to EoM and maximal sustainable power (Figure 2.1). This likely reflects observations of endurance athletes, although EoM is generally considered a better predictor of performance than other physiological variables in homogenous athletic groups (Fletcher, Esau, & MacIntosh, 2009). Ultra-endurance events may be seen as extensions of endurance activities (i.e. Ironman is a prolonged version of the Olympic distance triathlon and ultra-endurance marathons go beyond the 42.5 km of the traditional marathon), therefore there is logical basis for their supposition, albeit with modest differences in the level of contribution. However, at present the influence of exercise economy on ultra-endurance performance is equivocal, consequently the level of contribution of this physiological variable to performance is somewhat controversial (Millet, Hoffman, & Morin, 2012a).

Marongiu et al. (2013) assessed the oxygen cost of motion (C_m) during both running and cycling and found that the C_m at the respiratory compensation point (RCP) was associated with cycling time, but not running time during an Ironman triathlon (r = 0.82, p = 0.034). More recently, the oxygen cost of running (Cr) on level ground or 10% incline, at 60% of maximal aerobic speed was not correlated with ultra-endurance performance (Balducci, Clemencon, Trama, Blache & Hautier, 2017). Furthermore, difficulty arises when investigating the relationship between ultra-endurance performance and EoM as exercise efficiency is influenced by numerous modifiable factors. These include endurance training (Maughan & Leiper, 1983), the physiological, biomechanical and anthropometric characteristics of the athlete and the environmental conditions of the event (Saunders, Pyne, Telford, and Hawley, 2004), which have been partially illustrated in Figure 2.1. These modifyable factors indicate that the contribution of EoM to ultra-endurance performance is likely mediated by the specific characteristics of an ultra-endurance event.

Firstly, mechanical efficiency declines with increased temperature and altitude (Saunders, et al., 2004), therefore mechanical efficiencies may be compromised in athletes unaccustomed to these race conditions. Secondly, EoM is influenced by biomechanical factors that may be altered by the topography and technical difficulty of the course, along with the load associated with mandatory equipment and nutrition, required when competing in remote events. As an example, the cost of exercise is increased with additional load, ranging from 6% to 9% when walking with a load of 25.6 kg (Lloyd & Cooke, 2000) and 4% to 7% when running (7 to 14 $km.h^{-1}$) with a 1 kg pack (Sparks, Orme and McNaughton, 2013). Given that training can improve exercise economy, athletes who are accustomed to carrying the extra load, are likely to experience the smallest detriment in performance.

Millet, et al., (2012b), proposed that psychological and motivational factors influence the fraction of VO_{2max} sustained during an ultra-endurance race, however this was not adequately represented in their schematic (Figure 2.1). Furthermore, they failed to elaborate on the evidence underpinning the relationship between performance and these cognitive variables. However, further discussion of the psychological factors that influence ultra-endurance performance is outside the scope of this thesis. The comprehensiveness of their schematic is further questionable given that it fails to acknowledge the influence of nutrition on performance. This is despite observations that exogenous sources of energy and fluid consumption were integral to ultra-endurance performance independent of physiological predictors of performance (Marongiu et al., 2013). Equally, the label 'GI disorders' fails to represent the full range of GIS that may impair ultra-endurance performance (Section 2.3.5.2). Moreover, GIS are likely to have a negative impact on psychological and motivational factors with consequences for performance, which have not been represented in this schematic. In an attempt to provide a more comprehensive presentation of the physiological factors that influence ultra-endurance performance, Figure 2.2 has been revised to reflect the influence of nutrition and GIS on these variables (outlined in Section 1.4).

2.3 Nutrition and Ultra-Endurance Performance

Fuel availability is likely an integral component of ultra-endurance performance for two key reasons; firstly, low carbohydrate availability modulates the adaptations to training (Figure 2.2) that allow race performances to be maximised (Hawley & Morton, 2014; Perez-Schindler, Hamilton, Moore, Baar, & Philp, 2015); secondly, carbohydrate intake before and during competition are required to optimise fuel and substrate availability in order to meet the demands of the event (Leckey, Burke, Morton, & Hawley, 2016). Together, this enables the athlete to maximise their sustainable velocity (Figure 2.2), ultimately optimising race performance.

Research has indicated that ultra-endurance triathlons and running events lasting between ~12 hr and 24 hr are typically performed at moderate (~63% VO_{2max}) to low (~39% VO_{2max}) intensities (Barrero, Chaverri, Erola, Iglesias, & Rodríguez, 2014; Gimenez, Kerhervé, Messonnier, Féasson, & Millet, 2013). At similar intensities it is estimated that CHO oxidation ranges between 55% and 48% (1.60 $g.min^{-1}$ and 1.44 $g.min^{-1}$ for the moderate and low intensities, respectively), whereas fat oxidation ranges between 45% and 52% (0.60 $g.min^{-1}$ and 0.68 $g.min^{-1}$) (Costa et al., 2016; Costa, Snipe, Kitic, & Gibson, 2017; Van Loon, Greenhaff, Constantin-Teodosiu, Saris, & Wagenmakers, 2001). Therefore, CHO remains a major contributor to the energy demands of even the longest single day ultra-endurance events.

Furthermore, CHO is likely to be instrumental to ultra-endurance activities that include an element of high intensity activity. This may include the swimming segment of an Ironman triathlon, which has previously been performed at a high intensity (92.4% VO_{2max}) by a group of well-trained, non-professional athletes (Barrero et al., 2014). In addition, it is likely to include events that encompass periods of steep ascent, as HR data has indicated that almost a third of a mountain ultra-marathon was completed at >70% of HR_{max} (Clemente-Suarez, 2015).

At an exercise intensity of ~40% of the maximum workload, muscle glycogen oxidation can occur at a rate of 1.1 $g.min^{-1}$ (Van Loon et al., 2001). Theoretically, during a 24 hr race this would equate to a total of 1584 g of muscle glycogen, however, maximum glycogen storage is reported to be ~350-700 g depending on training status and the muscle mass characteristics of the individual athlete (Knuiman, Hopman, & Mensink, 2015). The limited glycogen storage capacity of skeletal muscle means that even in well-trained athletes with optimum glycogen stores, glycogen depletion can occur during activities lasting >90 min (Bartlett, Hawley, & Morton, 2015). However, liver glycogenolysis can provide an additional source of fuel, with rates typical ranging between 1.2 and 5.7 $mg.kg.min^{-1}$ (Gonzale, Fuchs, Betts, & van Loon, 2016), assuming appropriate pre-race CHO is consumed.

The implications of low muscle glycogen include impaired release of sarcoplasmic stores of calcium ions (Ca^{2+}), which are essential to muscle contraction (Ørtenblad, Westerblad, & Nielsen, 2013) and an increased reliance on fat oxidation (Achten & Jeukendrup, 2004). The former has been purported due to a moderate correlation between sarcoplasmic Ca^{2+} release rate and muscle glycogen stores ($r^2 = 0.41$, $p = <0.001$), coupled with Ca^{2+} release rates that returned to normal after glycogen restoration (Ørtenblad, Nielsen, Saltin, & Holmberg, 2011). In the latter, the contribution of fat to the fuel demands of prolonged exercise increased from 37 ± 3% to 46 ± 4% during the final 3 hr of a 6 hr cycle at 55% of VO_{2max} as glycogen contribution decreased (Rauch, Hawley, Noakes, & Dennis, 1998). The implications of this switch in fuel supply are likely to reflect the peak oxidation rates of fat during endurance exercise.

In a multi-trial experiment, where cyclists exercised for a set energy expenditure (2.8 MJ) at six specific intensities, lasting between 35 and 80 minutes, peak fat oxidation (0.6 ± 0.07 $g.min^{-1}$) was achieved at 64 ± 4% of VO_{2max} (Achten, Gleeson, & Jeukendrup, 2002). This was after an overnight fast when liver glycogen is likely to be compromised. However, muscle glycogen was not measured before or after the trial, therefore it is unclear whether the rate of fat oxidation was limited by the exercise intensity per sé or whether sufficient availability of muscle glycogen negated higher rates of fat oxidation (Jeppesen & Kiens, 2012). Nonetheless, this may help explain the intensity sustained during the cycling (62.4% of VO_{2max}) and running (63.3% of VO_{2max}) elements of an Ironman triathlon (Barrero, et al., 2014).

In trained athletes with high storage capacity, the onset of fatigue can occur with muscle glycogen of 250-300 $mmol.kg^{-1}$ dry weight (Knuiman et al., 2015). Furthermore, exhaustion coincides with muscle glycogen concentrations of ~25 $mmol.kg^{-1}$ of wet weight (~107 $mmol.kg^{-1}$ dry weight using conversion by Van Hall, Shirreffs, and Calbet (2000). The latter can occur after just 120 min of exercise (Hawley, Schabort, Noakes, & Dennis, 1997) at intensities that have been observed in an ultra-endurance triathlon i.e. ~64% of VO_{2max} (Barrero et al., 2014). This suggests that glycogen depletion is inevitable during ultra-endurance activities lasting >4 hr, unless the athlete self-selects a lower exercise intensity or ingests CHO during the event. Therefore, without appropriate nutritional strategies to provide exogenous sources of CHO for oxidation or to spare muscle glycogen, ultra-endurance performance is likely to be impaired.

In contrast, endogenous fat, even in lean athletes is available in sufficient quantities for prolonged periods of fat oxidation and therefore this substrates availability is unlikely to be a limiting factor for performance (Burke, Kiens, & Ivy, 2004). Instead, performance may be impaired by the maximum rate of fat oxidation, which typically occurs at moderate exercise intensities (~60% of maximum). Interestingly, a number of studies have indicated that fat oxidation can be enhanced by short-term (Burke, et al., 2000; Carey et al., 2001; Robins et al., 2005) and long term dietary manipulation (Volek et al., 2016), which may be of benefit to ultra-endurance activities when muscle glycogen stores are likely to be severely compromised and nutritional intake is likely to be insufficient (Section 2.3.1.3).

2.3.1 Nutrition Strategies and Ultra-Endurance Performance

Given that CHO is a prominent fuel source during single day, ultra-endurance events (Section 2.3), strategies to optimise CHO availability are likely to be most beneficial to performance. Carbohydrate loading and ingestion during exercise are key nutritional strategies capable of maximising glycogen stores and sparing endogenous CHOs during endurance exercise (Burke, Hawley, Wong, & Jeukendrup, 2011). The impact of such strategies on performance is commonly assessed separately, rather than in combination. However, due to the limited CHO storage capacity and the prolonged nature of ultra-endurance competition, multicomponent interventions may be warranted to determine the optimum combination of strategies to maximise fuel availability for such events.

2.3.1.1 Carbohydrate Loading

An early review by Hawley, Schabort, Noakes, & Dennis, (1997) concluded that during activities lasting >90 minutes, CHO loading improved endurance capacity and performance by ~20% and between 2 and 3% respectively. Although it should be noted that many of the studies included within this review had a very low CHO comparison group, which does not reflect the normal CHO intake (~5 $g.kg^{-1}$) of endurance athletes (Mahoney, Carnes, Wojcicki, Frith, & Ferry, 2016). Despite this, one may anticipate that CHO loading would be superior to normal CHO intake in preparation for prolonged endurance exercise as super-compensated glycogen levels associated with CHO loading (Hawley et al., 1997) would increase CHO availability. This would potentially be beneficial to performance in the latter stages of an ultra-endurance race or during events were carbohydrate intake may be compromised i.e. cross channel swimming or self-sufficient races.

Nevertheless, a robust CHO loading protocol, failed to show a benefit of CHO loading (9 $g.kg^{-1}$) compared to their double blind administered placebo (6 $g.kg^{-1}$) during prolonged cycling (Burke, et al., 2000). Cyclists completed a 100 km time trial in ~147 min and ~149 min for the CHO loading and placebo protocols respectively. The authors attributed this unexpected finding to the unique aspects of their study, which included the consumption of a pre-exercise CHO meal and the ingestion of a 7% CHO drink (at a rate to replace ~80% of sweat rate) during the experimental trial. Coupled with a more ecologically valid test of performance in the form of a self-paced 100 km cycling time trial and a placebo diet that was comparable with endurance athletes' daily CHO recommendations (Thomas, et al, 2016). This suggests that when cyclists consume a normal diet and ingest CHO both before and during endurance activities of <3 hr duration, 24 hr CHO loading (9 $g.kg^{-1}$) does not confer any benefit to performance. Furthermore, despite the superior muscle glycogen concentration prior to exercise in the CHO loading trial, the post exercise muscle glycogen concentration and the CHO utilisation did not differ between trials, suggesting that the 7% CHO solution during exercise, failed to spare muscle glycogen.

To date, there are no studies specifically designed to investigate the impact of CHO loading on ultra-endurance performance, in isolation or combined with CHO ingestion. In addition, there are no studies exploring the reliability of performance measures equivalent to ultra-endurance durations, possibly due to difficulties in recruiting participants for laboratory studies lasting >4 hr. It is likely that the sensitivity of a time trial equivalent to an ultra-endurance competition would be insufficient to detect meaningful differences in performance when manipulating nutritional intake using a crossover design. As such, studies attempting to replicate ultra-endurance events to assess the effectiveness of multicomponent nutrition strategies may be more suited to a matched groups study design.

2.3.1.2 Carbohydrate Ingestion During Exercise

The performance effect of CHO ingestion during physical activity has been extensively researched as indicated by the review articles produced by Pöchmüller, Schwingshackl, Colombani, and Hoffmann (2016), Stellingwerff and Cox (2014) and Colombani, Mannhart, and Mettler (2013). Overall, a performance benefit has been reported with CHO ingestion during prolonged activities lasting >90 min (Pöchmüller, Schwingshackl, Colombani, & Hoffmann, 2016) and 2 hr (Stellingwerff & Cox, 2014). The relationship between the dose of CHO and performance has been effectively explored in a multi-centre study of endurance cyclists (Smith et al., 2013). This study consisted of a series of experimental trials with cyclists completing a 20 km time trial, immediately after a 2 hr pre-load ride at 95% of their onset of blood lactate (~71% of VO_{2peak}). The cyclists (n = 51) who took part completed four trials in a random order, with cyclists prescribed drinks from 13 possible CHO doses, ranging from 0 to 120 $g.hr^{-1}$.

The main findings of this study indicated that there was a curvilinear relationship between CHO dose and performance; with the greatest improvement in time trial performance (4.7%) associated with the consumption of 78 $g.h^{-1}$ of CHO. It is worth noting that these cyclists completed each trial in a fasted state and maintained a normal diet in the 24 hr before each of their experimental trials, thus it is unlikely that they commenced the trials with maximum glycogen stores. Consequently, it is unclear whether such marked performance improvements would have been seen with such high rates of CHO ingestion, if glycogen stores had been optimised prior to these trials, like athletes would normally achieve during the hours before a race. Therefore, research is required to establish the optimum dose of CHO ingestion for peak performance in ultra-endurance activities, especially after optimum CHO loading to maximise muscle glycogen stores.

Many studies have reported that multi-transportable CHO fluids and gels are superior to single CHOs (>60 $g.h^{-1}$) for CHO oxidation (Pfeiffer, Stellingwerff, Zaltas, & Jeukendrup, 2010) and performance, during prolonged endurance activities (Currell & Jeukendrup, 2008a; Rowlands et al., 2015). This is typically after an overnight fast and no pre-exercise meal. A recent review concluded that benefits in endurance performance are likely when the rate and ratio of CHO ingested during exercise is between 1.3 - 2.4 $g.min^{-1}$ and 0.5 - 1.0:1 (for fructose:glucose/maltodextrin), respectively (Rowlands, Houltham, Musa-Veloso, Brown, Paulionis & Baily, 2015). Although, there appears to be marked variability in the magnitude of the performance benefit, with effect sizes ranging between 1.4 ± 0.9 and 14.6 ± 7.3 %. When CHO was ingested at a rate of 1.8 $g.min^{-1}$ (108 $g.hr^{-1}$), and a ratio comparable with commercially available products (i.e. glucose:fructose at a ratio 2:1), Currell and Jeukendrup (2008a) observed a higher power output during a time trial, immediately after 2 hr of steady cycling, compared to glucose alone (275 ± 10 vs 254 ± 8 W, $p < 0.05$). This translated to an 8% higher power output (95% CI: 4.8 to 12.1%). Interestingly, this was achieved in the absence of increased CHO oxidation.

In contrast, a recent large-scale study ($n = 71$) completed with triathletes competing in two half-Ironman distance events reported minimal difference in performance between trials when glucose:fructose (ratio 2:1) and glucose (~78 $g.hr^{-1}$) products were consumed (Rowlands & Houltham, 2017). The average time to complete these ultra-endurance events was 5 hr 0 min for glucose trial compared to 4 hr 58 min for the glucose:fructose trial, suggesting that CHO type had little influence on performance. This appears to be the only study comparing single and multi-transportable CHO in ultra-endurance activities; therefore further research is needed to determine the optimum rate and ratio of CHOs for this sporting discipline.

2.3.1.3 Short-Term High Fat, Low Carbohydrate Diet

The recent interest in short-term HFLC diets (Section 1.4) specifically relates to sporting disciplines most likely to benefit, such as prolonged sub-maximal endurance activities, when glycogen depletion and CHO availability are likely to be limiting factors for performance (Burke, 2015). Promoters of the HFLC diets such as Chang, Borer, & Lin (2017) have based their supposition of enhanced performance from HFLC diets on the widely accepted, enhanced fat oxidation after adaptation to both short (Burke, et al., 2000; Carey et al., 2001; Robins, Davies, & Jones, 2005) and long term HFLC diets (Volek et al., 2016). Similarly, improvements in fat oxidation have been observed after manipulating fat availability nicotinic acid (Leckey et al., 2016; Torrens et al., 2016), however, it is important to note that fatty acid availability is just one of the multiple possible mechanisms that may contribute to limitations in fat oxidation and subsequently performance. These mechanisms have been summarised by Jeppesen & Kiens, (2012), however, they are outside of the scope of this thesis, especially as they focus on high intensity activities, which may not be applicable to ultra-endurance competition.

In reality, enhanced fat oxidation has rarely translated into actual performance benefits (Robins et al., 2005), despite the proposed glycogen sparing affect of a HFLC diet (Carey et al., 2001). Volek et al. (2016) noted fat oxidation rates (1.54 $g.min^{-1}$ vs 0.67 $g.min^{-1}$) that were 2.3 fold higher in ultra-endurance athletes consuming a HFLC (10% CHO) diet compared to those consuming a low fat, high CHO (LFHC) (59% CHO) diet. Notably, the maximum fat oxidation rate observed after the HFLC diet was at a higher proportion of the athletes VO_{2max} (70.3% vs 54.9%). This suggests that these athletes would be able to sustain a higher intensity of activity in a glycogen-depleted state. However, Volek et al. (2016) failed to assess the effect of these superior oxidation rates on ultra-endurance performance. Similarly, Burke et al. (2017) reported increased fat oxidation rates that peaked at 1.57 ± 0.32 $g.min^{-1}$ for elite walkers while exercising at ~80% of VO_{2peak}, after following a three week ketogenic diet (<50 $g.d^{-1}$ CHO). Despite this, exercise economy was impaired and the enhanced fat oxidation did not translate into a performance benefit during a 25-race walk.

To date it appears that just two studies have explored the impact on performance of short-term HFLC diets compared to LFHC diets, during activities that meet the minimum threshold for ultra-endurance events (>4 hr) (Carey et al., 2001; Robins et al., 2005). The two studies differed in relation to several methodological factors including the experimental design (random crossover vs HFLC first), experimental trial (4 hr pre-load + 1 hr time trial vs 24 hr time trial, 2 hrs on and 2 hrs off) number of athletes (*n* = 7 vs *n* = 2), sporting discipline (cyclists vs rowers) duration of the diet (7 day vs 14 day), composition of the diet (69% fat and 16% CHO vs 60% fat and 30% CHO) and nutrition during the trials (7% CHO vs 60% fat + 30% CHO + 10% protein) (Carey et al., 2001; Robins et al., 2005), however, both studies provided evidence of enhanced fat oxidation (lower RER) following the HFLC diet. Despite this, only Robins et al. (2005) observed a performance benefit. The scope of this finding is limited as the participant numbers were limited to two and they both completed the HFLC diet first. Therefore, it is not possible to determine if the findings were statistically significant or whether the findings were associated with trial order.

In addition, it is unclear whether the sensitivity of individual time trials (i.e. coefficients of variation typically <5% in trained individuals) extends beyond activities that are 100 km or 90 min (Currell & Jeukendrup, 2008b), casting doubt on the credibility of the performance benefit observed by Robins at al. (2005). Nevertheless, the duration of the rowing event (12 hrs) was considerably longer than the cycling event (5 hrs) and therefore more likely to benefit from enhanced fat oxidation. This is especially true, given that the rowers, unlike the cyclists did not CHO load prior to the experimental trials (Robins et al., 2005). Further studies are warranted to enhance current understanding of the effect of increased fat oxidation on ultra-endurance performance, when combined with CHO loading and CHO ingestion. While prolonged (glycogen depleting) ultra-endurance events are most likely to benefit, recruitment of sufficient participants to studies of similar duration to Robins et al., (2015) is unlikely. Instead, future studies should explore whether this multicomponent nutrition strategy is beneficial to performance during self-paced activities, which replicate competition. Self-paced competitive events are likely to include short periods of high intensity activity (inclines and chasing competitors) and steady state, moderate activity, therefore likely to benefit from strategies to enhance CHO and fat availability (Chapter 4, study 3).

2.3.2 Nutrition Recommendations for Ultra-Endurance Performance

Nutritional recommendations for athletic performance have been produced in a collaborative position statement from the Academy of Nutrition and Dietetics (Thomas et al., 2016). This document includes macronutrient, micronutrient and fluid recommendations for the athlete's habitual diet (preparation diet) along with acute fueling strategies (performance diet) that aim to optimise performance. It is outside the scope of this thesis to review these recommendations in full; instead this section of the literature review will consider the acute fuelling strategies for before and during ultra-endurance activities.

Fueling the ultra-endurance athlete requires consideration of the nature, intensity and duration of the proposed event, the athlete's individual characteristics (age, gender and body composition) (Thomas et al., 2016) and the limitations to fuel availability (Knuiman et al., 2015). Given that ultra-endurance events can be continuous single day events lasting 4 to 24 hr (Stuempfle, Hoffman, Weschler, Rogers, & Hew-Butler, 2011) or consist of several days in either a multi-stage (Costa et al., 2013; Dempster, Britton, Murray, & Costa, 2013) or semi-continuous nature (Hulton et al., 2010) the intensity of the activity can vary considerably, as indicated in section 2.3 of this literature review. Furthermore, many ultra-endurance events require athletes to be self-sufficient (Mccubbin, Cox, & Broad, 2016), while others permit the use of a support crew (Knechtle, Chandler, & Pitre, 2007) to provide nutrition throughout the race. As such the nutrition recommendations for optimum performance need to be interpreted within the context of the challenges that are associated with such events, which is single day events for the purpose of this thesis.

Many of the sport nutrition guidelines are presented in relation to the athlete's body mass to allow an individualised approach to nutrition (Burke et al., 2011). In addition, they emphasise strategies to optimise fuel availability in relation to the limited CHO storage capacity of muscle and liver (Hawley, et al., 1997; Jeukendrup, 2014). Given that fat oxidation is generally provided from the large pool of endogenous fat stores, nutrition recommendations for ultra-endurance athletes are predominately focused on CHO. There are a number of bespoke CHO guidelines for prolonged activities (lasting >60 or 90 min), however, only the total daily CHO requirements specifically target activities equivalent to ultra-endurance events i.e. >4 hr in duration (Burke et al., 2011; Jeukendrup, 2014; Thomas et al., 2016).

2.3.2.1. Pre-Event Nutritional Recommendations

In preparation for activities lasting more than 90 min CHO loading is continuously promoted to enable the athlete to maximise their muscle glycogen stores (Burke et al., 2011; Hawley, et al., 1997; Thomas et al., 2016). This is despite failure to observe a difference in performance between moderate and high CHO loading, when CHO was ingested during prolonged exercise (2.3.1.1). The most recent CHO recommendations are for 10 to 12 $g.kg^{-1}.day^{-1}$ for between 36 and 48 hr, with cautionary guidance to avoid detrimental consequences to performance i.e. GIS associated with high fibre intake (Thomas et al., 2016). Suggesting that an individualised approach to CHO loading is required, addressing the athlete's tolerance to CHO. When athletes are able to tolerate 10 $g.kg^{-1}day^{-1}$ a single day CHO loading protocol has proven to be as effective as a 72 hr protocol, providing athletes are rested (Bussau, Fairchild, Rao, Steele, & Fournier, 2002). In this study, an increase of 90% in muscle glycogen (95 to 180 $mmol.kg^{-1}$ of wet weight) was observed after 24 hr, with no significant differences in glycogen stores after 3 days (p >0.05).

A second strategy that aims to optimise glycogen stores is the consumption of a CHO rich meal (i.e. 1-4 $g.kg^{-1}$ of CHO), 1-4 hr before an event lasting >60 min (Burke et al., 2011). This can be confusing to athletes, as for a 70 kg athletes, this would range between 70 and 280 g of carbohydrate, which equates to 3 to 14 medium bananas, respectively. In relation to ultra-endurance athletes, this can present as a challenge because races can start as early as 06:00 hr. Consequently, CHO rich snacks and fluids may be a more practical source of CHO for such events. The composition of the pre-exercise meal has been explored in relation to the glycaemic index and more recently the glycaemic load (O'Reilly, Wong, & Chen, 2010).

A comparison of high and low glycaemic index pre-event meals reported a significantly faster performance during a 40 km time trial following the low glycaemic meal (93 ± 8 min vs 96 ± 7 min, p = 0.009) (Moore, Midgley, Thurlow, Thomas, & Mc Naughton, 2010). Interestingly, during this trial several cyclists experienced hypoglycaemia after both protocols, further emphasising the need for individualised nutritional recommendations, in order to avoid detrimental effects on performance. Recently, interest has been shown in the potential role of a low glycaemic index pre-training meal in inducing training adaptations favourable to endurance performance (McNaughton, Bentley and Sparks, 2016), however, research in this area is in its infancy. Another crucial observation is that the glycaemic index of the CHO food is not an important factor for performance or substrate availability when the athlete is consuming a meal that has a mixed macronutrient composition (O'Reilly et al., 2010).

2.3.2.2 During-Event Nutrition Recommendations

Consensus guidelines for ingesting CHO during prolonged physical activity recommend 90 $g.hr^{-1}$ of multi-transportable CHO (Jeukendrup, 2014). Although, in the absence of conclusive empirical evidence (Section 2.3.1.2) the recommended ratio of the multi-transportable CHO (2:1 glucose:fructose), appears to be based on expert opinion, rather than peak oxidation rates (Jentjens & Jeukendtup, 2005; & Jeukendrup, 2010). In practice, the foods and drinks consumed by ultra-endurance athletes have a unique saccharide profile (glucose to fructose ratio ranging between 2.2:1 and 5.3:1), with only 8.8% of foods having the recommended combination of glucose:fructose (Wilson, Rhodes & Ingham, 2015). Furthermore, ultra-endurance athletes typically consume a combination of foods and fluids containing fat and protein in addition to multiple-transportable CHO (Knechtle et al., 2007; Kruseman, Bucher, Bovard, Kayser, & Bovier, 2005; Mccubbin et al., 2016), suggesting that the current CHO recommendations may be unattainable.

2.4 Adequacy of Nutritional Intake During Training and Competition

The adequacy of ultra-endurance athlete’s nutritional intake has been explored in numerous case studies and small-scale observational studies using a variety of techniques to estimate energy expenditure and energy intake.

2.4.1 Estimating Energy Expenditure

Doubly labelled water (DLW), the gold standard for estimating total energy expenditure is compatible with both laboratory and field studies and provides little disruption to physical activity behaviour (Westerterp & Westerterp, 2017). Despite this it does not appear to have been used during ultra-endurance studies, possibly due it's inhibitive cost. The accuracy of alternative methods used to estimate energy expenditure has been established by direct comparison to the gold standard and summarised in a review by Ainslie, Reilly, and Westerterp (2003). In laboratory conditions, energy expenditure can be estimated with direct and indirect calorimetry by measuring heat loss and oxygen consumption respectively (Westerterp & Westerterp, 2017), however, few studies of ultra-endurance energy expenditure have been conducted in laboratory conditions (Linderman & Laubach, 2004). The indirect calorimetry method can be conducted in the field, however, portable gas analysis systems, which include backpack and harness would be impractical for ultra-endurance athletes who often carry their nutrition in a backpack (observations), and add to already high energy expenditure.

As such, energy expenditure is often estimated during ultra-endurance competitions using HR as it has been established that there is a strong relationship between these two variables, during endurance exercise (Ainslie et al., 2003). Mapping the individual's HR against their measured oxygen consumption at various workloads enhances accuracy of HR generated energy expenditure. This method has shown variability in a group of 18 speed skaters (aged 18.6 ±1.3 yr), with energy expenditure estimated from HR varying between -10.6 to 15.1%, compared to DLW (Ekelund, Yngve, Westerterp, & Sjöström, 2002).

Other methods used in such studies involve standardised estimates of energy expenditure, based on average speed (McCole, Claney, Conte, Anderson, & Hagberg, 1990; Minetti, Moia, Roi, Susta, & Ferretti, 2002), which allow participants to be recruited on the day of a specific race and have very little participant burden. The variability in methods used to estimate energy expenditure means that direct comparison of the level of energy balance cannot be made between studies. Despite this, high rates of energy expenditure have been reported during a 54 km mountain ultra-marathon (5197 ± 489 kcal) lasting 6 h 44 min (Ramos-Campo, et al., 2016) and during a 24 hr treadmill protocol (12,425 kcal) (Linderman & Laubach, 2004), using the same metabolic equation.

2.4.2 Estimating Energy Intake

Assessing the accuracy of tools used to estimate energy intake is limited by the availability of a suitable criterion method against which they can be measured (Trabulsi & Schoeller, 2001). Common tools used in research include weighed and estimated dietary records, 24 hr recalls, observations by trained staff, food frequency questionnaires (FFQ) dietary recall and dietary history. The strengths and limitations of each method have been reviewed by Shim, Oh, and Kim (2014) and they conclude that with due consideration to the limitations, the method of choice should reflect the research objective, available resources and overall research design.

The nutritional intake of ultra-endurance athletes during training has typically been recorded by athletes, using household measures to estimate portion sizes (Martin, Martin, Collier, & Burke, 2002; Peters & Goetzsche, 1997; Zalcman et al., 2007). Such estimates are associated with considerable underreporting (11.9 to 44.0%) (Poslusna, Ruprich, de Vries, Jakubikova, & van't Veer, 2009), however, control measures such as remote food photography have been successful at mitigating a large proportion of this error. Martin et al. (2008) observed a small underestimate of energy intake (6.6%) in free-living individuals who estimated their food intake with the assistance of food photography.

Research conducted with ultra-endurance athletes has predominately been concerned with energy and CHO intake during competition. As such, the methods used to record nutritional intake are often limited by the logistics of the event. Some studies have used direct observations by trained researchers or dietitians (Bescós et al., 2012; Kruseman, Bucher, Bovard, Kayser, & Bovier, 2005; Moran, Dziedzic, & Cox, 2011), while others have relied on the athlete's support crew (Black, Skidmore, & Brown, 2012) or dietary recalls supplemented by a list of the athletes planned nutrition and collection of wrappers after the race (Clemente-Suárez, 2015). One particular study had the support of 30 researchers who were located in pairs at each of the 15 aid stations (Kruseman et al., 2005), which is unlikely to be feasible for many smaller studies. The reliability of these methods for estimating energy intake have not been formally assessed, however, records completed by trained researchers are likely to be superior to those recorded by the athletes support crew, due to their vested interest and skill level.

When researcher observations were not possible, strategies to enhance the accuracy of the records either by providing training, instructions or follow-up interviews and phone calls to verify nutritional intake were implemented. Furthermore, all studies reviewed (below) used professional dietary analysis software appropriate to the country the study was conducted in. In the event a nutritional product was not available in the individual software database nutritional information was obtained from the product manufacturers or information on the wrappers retained by the athletes. Similar to the energy expenditure estimates, the variability between studies limits the ability to directly compare the findings of one study to another.

2.4.3 Nutritional Balance During Training and Competition

The energy intake, expenditure, and subsequently energy balance has been reported for ultra-endurance triathletes, runners and cyclists competing in single day events

(Black et al., 2012; Clemente-Suárez, 2015; Kimber, et al., 2002). In general, considerable energy deficits, which cannot be explained by measurement error, have been reported within all three athletic disciplines. Daily energy deficits during competition have been reported to range between 1889 and 4732 kcal for runners (Clemente-Suárez, 2015; Kruseman et al., 2005), 5123 and 5973 for triathletes (Kimber et al., 2002) and as much as 9915 kcal for cyclists (Bescós et al., 2012), during competition. While this indicates that the energy intake during competition is suboptimal, it fails to consider whether athletes attempt to compensate for this in the lead up to competition, or in subsequent days.

A number of studies have also compared the CHO intake of athletes to best practice guidelines. Intakes have ranged from 35.4 $g.hr^{-1}$ to 44 $g.hr^{-1}$ (Clemente-Suárez, 2015; Moran et al., 2011) for runners and ~49 $g.hr^{-1}$ in cyclists (Bescós et al., 2012) during single day events. These intakes are within the recommendations for endurance activities lasting 1 - 2.5 hr and therefore may be considered inadequate for at least some ultra-endurance events (Thomas, et al., 2016). This is particularly likely during events that include substantial periods of high intensity exercise or those that are completed after an overnight fast or insufficient CHO-loading. Interestingly, a female athlete that recorded her intake for a 100 km foot race matched her individalised CHO target of 40 $g.hr^{-1}$, which was negotiated with her sports dietitian based on her tolerance level. During this race she was able to avoid GIS, which may be regarded as more important for overall performance, given that runners have sited nausea as a reason for non-completion (illustrated in Figure 2.2) (Hoffman and Fogard, 2011).

Together this literature indicates that during single day ultra-endurance events, energy intake is considerably lower than energy expenditure and CHO intakes are below current recommendations. This emphasises the importance of acute fueling strategies in the days and hours leading up to an ultra-endurance event, in order to optimise fuel availability and consequently performance (Thomas et al., 2016). A high CHO intake (9 $g.kg^{-1}.day^{-1}$) 24 hrs prior to competition is capable of increasing muscle glycogen stores above moderate (6 $g.kg^{-1}.day^{-1}$) CHO intake (Burke, et al., 2000). Thereby increasing CHO availability for competition. However, CHO intake recorded in the 24 hr before competition (3.5 to 7.25 $g.kg^{-1}.day^{-1}$) appears to be suboptimal, from the limited studies available (Armstrong, 2012; Havemann & Goedecke, 2008; Peters & Goetzsche, 1997). Although, failure to consume such high volumes of CHO could suggest that they may be higher than required for some athletes i.e. less trained athletes, with a lower glycogen storage capacity or athletes who consume sufficient CHO during exercise to prevent critical glycogen levels (Section 2.3).

In order to prepare for competition, ultra-endurance athletes are likely to engage in prolonged training sessions on a regular basis. To date, little is known about the training diet of ultra-endurance athletes, however it is possible that observed energy and CHO deficits during competition, may be commonplace in the athletes habitual diet. These nutritional inadequacies may have considerable consequences for the health and performance of such athletes (Mountjoy et al., 2014). Furthermore, no studies have explored the acute fuelling strategies in the 24 hrs prior to a prolonged training session. As such, future studies exploring the adequacy of ultra-endurance athletes' nutritional intake should consider both the pre-race and pre-training nutritional practices in addition to training and competition intake (Chapter 3, study 1).

2.5 Challenges to Energy Balance and Carbohydrate Intake

The reasons for the energy deficits and suboptimal CHO intake during ultra-endurance competition and to a lesser extent training warrant further investigation. Specifically, research exploring the factors that influence ultra-endurance athletes nutritional intake could prove beneficial to athletes and the professionals supporting them by (i) identifying barriers to optimum nutritional intake and (ii) providing a greater understanding of the motives behind food choices during training and competition. This information could be used to devise bespoke nutrition interventions to improve the nutritional intake in this critical period in an attempt to enhance training adaptations and ultimately performance.

2.5.1 Influence of Nutritional Knowledge on Nutritional Intake

The nutrition knowledge of athletic populations has been explored for a number of decades (Heaney, 2011; Parr, Porter, & Hodgson, 1984; Spronk, 2014; Werblow, Fox, & Henneman, 1978). This likely reflects a combination of historic opinion that nutrition was essential to performance (Applegate & Grivetti, 1997), along with current understanding of the integral role of nutrition to training adaptations (Bartlett, Hawley, & Morton, 2015). In addition, nutrition knowledge has been regarded as a modifiable factor that can influence nutritional choice (Trakman, 2016) and consequently the adequacy of an athletes diet.

2.5.1.1 Nutrition Knowledge and Assessment Tools

The nutritional knowledge of athletic populations has been extensively reviewed in recent years (Heaney, O'Connor, Michael, Gifford, & Naughton, 2011; Spronk, 2014; Trakman, 2016). Overall the nutrition knowledge of athletes varied considerably between studies, ranging from 33.2 to 83.7% (Heaney, 2011; Trakman, 2016).

Although, it should be noted that direct comparison of the level of nutrition knowledge between studies has not been permitted due to the contrasting tools used. Tools to assess nutrition knowledge include general nutrition questionnaires (Parmenter & Wardle, 1999; and Spendlove, Heaney, Gifford, Pvan, Denyer, & O'Connor, 2012) and sport-specific nutrition questionnaires (Furber, Roberts, & Roberts, 2017; Zinn, Schofield, & Wall, 2005). Sport-specific questionnaires have advantages over general nutrition questionnaires when assessing the knowledge of particular athletes, as they include nutrition questions pertinent to the demands of the particular sport (Zinn et al., 2005). Specifically, addressing key nutritional issues associated with prolonged endurance exercise, such as fluid requirements to minimise the risk of hyponatramia (Sawka, et al., 2007). Despite this, the comprehensiveness of individual questionnaires for assessing the knowledge of athletes appears to vary considerably, with the sports nutrition questionnaires developed by Devlin and Belski (2015) and Zinn et al. (2005) amongst the most comprehensive reviewed according to Trakman, (2016).

Despite this, sports specific questionnaires are likely to lack specificity for ultra-endurance athletes. Firstly, because top-level ultra-endurance athletes are likely to have a different body composition profile compared to elite athletes competing in other sports such as those with more emphasis on strength and power or intermittent activities. Furthermore the nutrient and hydration demands of prolonged exercise are considerably different to shorter duration activities (Sawka et al., 2007; Thomas et al., 2016). Zinn et al. (2005) included questions in relation to muscle mass gain for rugby players, which is less important to ultra-endurance athletes who may benefit from being lighter. In addition, their fluid questions were based on recommendations associated with shorter duration activities i.e. did not acknowledge the need for sodium replacement for prolonged competition. Therefore to assess the nutrition knowledge of ultra-endurance athletes there is a need for a bespoke nutrition knowledge questionnaire that reflects nutritional research for ultra-endurance performance.

2.5.1.2 Nutrition Knowledge and Diet Quality

The relationship between knowledge and nutritional intake has been less commonly reported, with only nine of the 29 studies reviewed by Heaney et al., (2011) exploring the association between these variables. These findings suggest that knowledge was at best moderately correlated (r = 0.23 to 0.44, p <0.05) with nutritional intake (Heaney et al., 2011; Spronk, 2014). Moreover, Spronk (2014) reported that knowledge was not associated with nutritional practices in 28.6% of the studies they appraised. The variable relationship between nutrition knowledge and intake, in part reflects the differences in the aforementioned knowledge questionnaires, along with the range of tools used to quantify the athletes nutritional intake. In the latter, nutritional intake has been documented using food diaries, 24 hr recalls or food frequency questionnaires, which rely on the honesty of the participants. In addition, due to the absence of a criterian method to validate self reported nutritional intake, it is not possible to detect reporting error (Trabulsi & Schoeller, 2001).

Furthermore, some studies have explored the relationship between knowledge and specific nutrients or food groups (i.e. portions of fruit and vegetables), while others have focused on healthy habits or diet quality as a whole. None of these studies assessed the level of nutrition knowledge in comparison to nutritional recommendations for optimal performance and therefore provides limited insight into the influence of knowledge on the adequacy of nutritional intake for performance.

Furthermore, there are no studies exploring nutrition knowledge of ultra-endurance athletes. Given the potential negative consequences of inadequate fuel and fluid replacement strategies and the observed positive influence of knowledge on nutritional intake previously mentioned, there is a clear rationale for exploring the nutrition knowledge of ultra-endurance athletes (Chapter 3, study 1).

2.5.2 Influence of Food Choice on Nutritional Intake

In addition to nutrition knowledge, numerous social and physical influences in an athlete's environment are believed to affect their food choices (Long, Perry, Unruh, Lewis, & Stanek-Krogstrand, 2011). Underpinning research in this domain are theories of food choice, which attempt to explain the process involved in food selection.

2.5.2.1 Models Underpinning Food Choice

An early conceptual model developed using a grounded theory approach by Furst, Connors, Bisogni, Sobal, and Falk (1996) namely the 'food choice process' model, introduced the dominance of the 'life course' to food choice. They proposed that through the life course perspective, individuals are exposed to personal roles and environments (social, cultural and physical) that shape the factors that influence their individual food choices. Starting with early childhood experiences, transitions through their life including college, work, marriage and consideration of anticipated future events, such as retirement, alter the drivers of food choice. A number of subsequent qualitative studies have incorporated the life course perspective as a core component of their conceptual models (Bisogni, Connors, Devine, & Sobal, 2002; Bisogni, Jastran, Shen, & Devine, 2005; Devine, Connors, Bisogni, & Sobal, 1998), providing evidence that further reinforces the influence of the life course on an individuals food choices.

In contrast, the life course was a less dominant component of other models of food choice (Dibsdall, Lambert, & Frewer, 2002), which may reflect to some extent the different theoretical approaches underpinning their chosen qualitative research methodology. Grounded theorists (Bisogni et al., 2002) build theory from the data with a focus on understanding social processes, whereas interpretive phenomenological analysis (IPA) (Dibsdall et al., 2002), focuses on the meaning people attach to their experiences (Braun & Clarke, 2013). As such, the direction of questioning for IPA explores the individual’s thoughts and feelings while making food choices and therefore it is likely to be dominated by the current period. In contrast, grounded theory, which explores the processes that lead to a specific food selection, lends itself more to a historical perspective that draws on past experiences. The influence of the life course on the food choices of ultra-endurance athletes may be anticipated given that they are likely to have been exposed to a range of environmental influences in their life and past athletic experiences.

Another key component to the food choice process is the ‘personal system’, which includes two core components (i) the negotiation process that involves weighing up different factors that influence their food choice and (ii) the strategies such as heuristic cues that simplify the food choice process and form routines and habits (Furst et al., 1996). The negotiation process involves cognitive processes as people make food choice decisions; however, the heuristic cues developed from exposure to similar food choice situations are proposed to reduce the effort involved in making a food decision (Sobal & Bisogni, 2009). Although the personal system (later termed the ‘personal food system') has not been reproduced in all other conceptual models

(Bisogni et al., 2005; Delaney & McCarthy, 2011; Dibsdall et al., 2002), the negotiation element is often implied through multi-directional arrows and Venn diagrams that intimate that several factors influence food choices in a given situation. This negotiation process is likely to exist for ultra-endurance athletes given that they are generally recreational athletes, meaning they are likely to negotiate food choices within the demands of their large training volumes, family and work commitments.

Existing conceptual models provide rich detailed narratives that help to understand the food choice process and the factors that influence food selection of a population in a given situation. They are however, limited in scope as they are largely developed from small qualitative studies that are not transferable to ultra-endurance athletes. Equally the recently developed DONE framework (Stok et al., 2017), which used a quantitative approach to integrate food choice research from all domains, providing an interdisciplinary model, is unlikely to fully address potential influencing factors for ultra-endurance athletes. The advantage of this framework is the interactive nature that allows emerging factors to be added, however, the richness of the food choice experience is lost by the numerical analysis. Therefore future studies are likely to benefit from combining qualitative and quantitative approaches to provide both a comprehensive and rich analysis of the factors that influence food choices of ultra-endurance athletes.

2.5.2.2 Tools to Assess the Factors Influencing Food Choice

A number of researchers have developed quantitative surveys in order to explore the factors that influence the food choices of population groups. A historical survey coined the ‘food choice questionnaire’, which was developed by Steptoe, Pollard and Wardle, (1995) has been adapted in recent years to reflect changes in current world issues such as environmental concerns and animal welfare (Fotopoulos, Krystallis, Vassallo, & Pagiaslis, 2009; Lindeman & Väänänen, 2000). While they all provide evidence of reliability, content and construct validity, the factors that make up the individual questionnaires were developed to investigate habitual food intake in the general population. As such, in their current format they are unlikely to consider the full range of factors that contribute to an ultra-endurance athlete's food choices. A recent survey, conducted by Turner-McGrievy, Moore, & Barr-Anderson, (2016) explored the factors that influenced the food choices of a group of endurance and ultra-endurance athletes, however, it focused on identifying the main reason for their habitual diet, rather than training and competition. Consequently, it failed to provide any indication of the factors that may prevent optimal nutrition for competition. Future studies should consider the range of factors likely to influence the food choices of the ultra-endurance athlete in relation to the training and competitive environment to enhance our understanding of the challenges to optimum nutritional intake (Chapter 3, study 2).

2.5.2.3 Factors Influencing Food Choices in Athletic Populations

A recent literature review has presented details of the main factors proposed to influence the food choices of athletes (Birkenhead & Slater, 2015). These factors have been categorised into five main areas, with between one and five factors in each category (Table 2.1). While nutrition knowledge has generally been explored in isolation using quantitative questionnaires (Heaney, et al, 2011), qualitative studies have explored in more depth the factors influencing food choice from the perspective of the athletic population. This has allowed a greater range of factors to emerge from the data. In the latter, the strength and pervasiveness of each factor gives some indication to the level of contribution that individual factors make to the food choices of a group of athletes, however, studies are scarce. Existing research exploring the factors that contribute to the food choices of athletes in team and endurance sports has highlighted some common factors, but also some unique to the population of interest. Therefore to gain a detailed understanding of the factors influencing the food choices of ultra-endurance athletes during training and competition, future studies should be context specific.

A common feature for athletes taking part in both endurance and team sports was the importance of selecting ‘healthy’ foods, which were regarded as low in fat and sugar and avoidance of fast foods that may impair performance (Long et al., 2011; Robins and Hetherinton, 2005; & Smart & Bisogni, 2001). Although, for a group of triathletes, somatic complaints, performance, trust, routine and preferences were more influential to their food choices (Robins & Hetherington, 2005). The routine factor reflected both work and competition practices, as these athletes were not full time professional triathletes. The majority of ultra-endurance athletes are regarded as non-professional or recreational and therefore it may be anticipated that both work and competition routines will be influential to the ultra-endurance community, however, work routines are less likely to influence the food choices for competition.

Table 2.1. Summary of factors influencing the food choices of athletes

Categories	Influences
Physiological and biological	Hunger and appetite
	Macronutrient balance
	Fat-free mass, resting metabolic rate and hunger
	Taste and food preferences
	Gastrointestinal discomfort
Lifestyle, beliefs and knowledge	Lifestyle and motives for participating in sport
	Health beliefs
	Nutrition knowledge
Psychological	Body image and weight control
	Hedonic hunger
Social	Meal patterns, availability, social facilitation and marketing
	Culture and religion
Economic	Cost and income

Adapted from Birkenhead & Slater, (2015).

Another common feature across athletic groups was the influence of time (Long et al, 2001; & Smart & Bisogni, 2001), with specific factors becoming more dominant to the athletes food choices at key points during the athletic calendar (Figure 2.4). Interestingly, ice-hockey players indicated that during the competitive season, tasteful foods that were regarded as high in fat were governed by strict rules that meant that they were consumed infrequently, whereas in the offseason they were consumed more liberally. These rules formed habits that were situation specific (Smart & Bisogni, 2001). This feature of the athletes food choice was akin to the strategies within the personal food system referred to in the food choice process model (Section 2.5.2.1) (Furst et al., 1996). A similar pattern may be envisaged for ultra-endurance athletes, as priorities are likely to change when races and prolonged training sessions are anticipated in the immediate future.

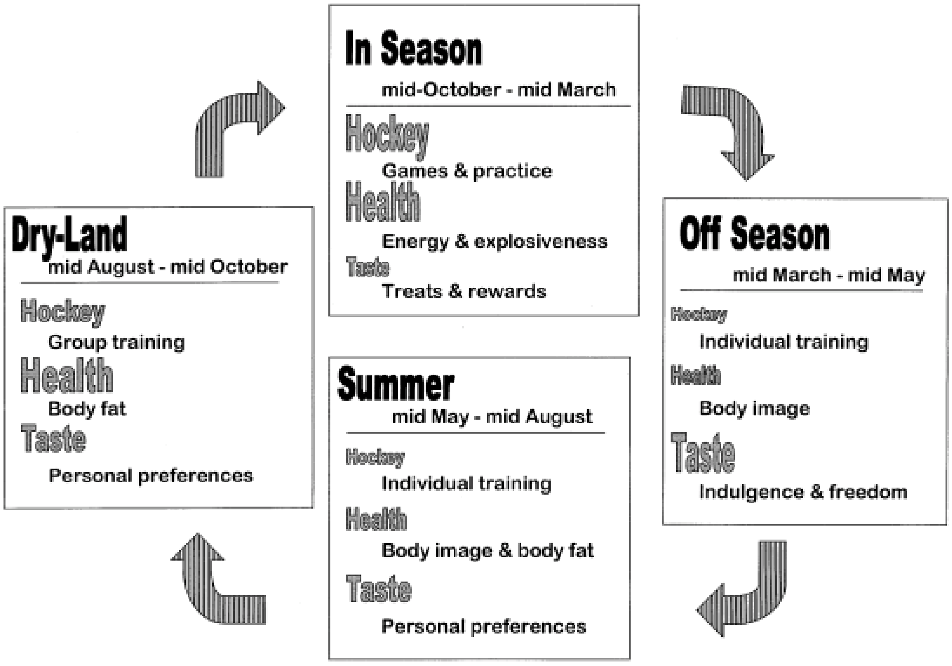


Figure 2.4. Personal systems involved in the seasonal food choices of ice-hockey players (Smart & Bisogni, 2001, p. 64).

A factor unique to football players was the nutrient content of foods and the planning of hydration strategies (Long et al., 2011). These athletes discussed the importance of protein and secondly CHOs for performance. Given the high CHO demands (Stellingwerff & Cox, 2014) of ultra-endurance competition, one might speculate that this would be a dominant consideration towards ultra-endurance athletes' food choices. Although it should be acknowledged that the interview schedule used during the interviews with footballers specifically asked about their fueling strategy (Long et al., 2011) and may have provoked a socially desirable response.

A series of focus groups conducted with 13, UK triathletes identified that the specific GI symptom 'nausea' was an influential factor in their food choices (Robins &

Hetherington, 2005). Consequently, athletes manipulated the timing of their food consumption, based at times on the type of training session they were about to complete. This was demonstrated by one individual who ate before running and cycling sessions, but not swimming, stating ‘but for swimming I usually try not to, because I feel like I’d throw up if I did’ (Robins & Hetherington, 2005, p. 448). A common theme for those who experienced GIS was the implementation of strategies to prevent them occurring, including the avoidance of specific nutritional products or withholding nutritional intake. Dietary restriction as a consequence of GIS and sensory issues has been reported by a group of ultra-endurance athletes during a multi-stage event (McCubbin, et al., 2016), providing some insight into the potential reasons for the negative energy balance and insufficient CHO. The relationship between GIS and nutritional intake will be explored in more detail in the subsequent section (2.5.3) due to the high prevalence of symptoms amongst ultra-endurance athletes (De Oliveira, Burini, & Jeukendrup, 2014).

2.5.3 Exercise Induced Gastrointestinal Symptoms and Nutritional Intake

The association between exercise induced GIS and the adequacy of an ultra-endurance athlete’s diet during competition is complex and appears to be bidirectional in nature (Figure 2.2). The majority of research in this area is observational or based on exercise interventions that are shorter than ultra-endurance exercise, which limits the scope of current findings. Moreover, research in this field is complicated by the intricate circulatory and neuroendocrine pathways, proposed to be involved in the development of GI damage (Section 2.5.3.1) and the range of tools used to quantify the incidence and severity of symptoms (Section 2.5.3.2).

Dietary intake before and during exercise has been implicated in both the development and prevention of GIS (Pfeiffer, Coterill, Grathwohl, Stellingwerff, & Jeukendrup, 2009; Rehrer et al., 1992; Stuempfle et al., 2013). An early study reported that consumption of a higher quantity of fat or protein 30 minutes prior to a variety of half-Ironman triathlons was associated with greater prevalence of upper GIS, whereas fibre intake prior to the event was associated with intestinal cramps post-Ironman (Rehrer, et al., 1992). In contrast, fat and fluid consumption during a 100-mile foot race have been proposed to be protective against GIS (Stuempfle et al., 2013).

Two recent observational studies exploring the relationship between incidence and severity of GIS, and fluid intake during competition have also presented somewhat conflicting findings. Stuempfle et al., (2013) noted that ultra-marathon runners with GIS had lower fluid intakes (5.9 ± 1.6 $ml.kg^{-1}.hr^{-1}$ compared to 10.9 $ml.kg^{-1}.hr^{-1}$), whereas Costa, et al, (2016) reported higher water intakes (total of 65 ± 23 $ml.kg^{-1}$ compared to 51 ± 22 $ml.kg^{-1}$, $p < 0.01$) for athletes with GIS during a MSUM. However, in the latter study a greater symptom severity was associated with a lower (-902 ml, $p = 0.01$) water intake and greater energy deficits. Due to the absence of the timing of symptoms it is not possible to establish whether the lower fluid intake was the cause or consequence of higher symptom severity. In contrast, a large observational study of ultra-endurance runners ($n = 280$) concluded that the specific GIS nausea and vomiting were not associated with electrolyte or fluid imbalances during a 161 km foot race (Hoffman & Stuempfle, 2016). This unique observation should be interpreted with caution, as this conclusion appears to be unsubstantiated. Firstly, because the serum sodium concentration of both those with and without nausea and vomiting were within the normal range and secondly, the analysis of fluid balance did not consider urine output.

Carbohydrate type and concentration has also been associated with GIS, albeit with similarly equivocal findings. In one study, consumption of hypertonic fluids (>325 mOsm.kg^{-1}) during the cycling component of a half-Ironman triathlon resulted in a higher prevalence (42% compared to 11%) of vomiting or urge to vomit (Rehrer et al., 1992), although this relied on memory recall over a prolonged period (6-7 months). In contrast, neither Wilson et al, (2015) nor Pfeiffer et al., (2012) found a relationship between total CHO and GIS. However, Pfeiffer et al., (2012) observed a modest association between high volumes of CHO intake and individual GIS (nausea and flatulence r = 0.34 and r = 0.35, p <0.05, respectively) for their triathletes. Furthermore, when the saccharide composition of the CHO consumed was analysed separately, a moderate correlation between glucose intake and GI distress (r = 0.469, p = 0.037), but not fructose was observed (Wilson et al., 2015). The comparable CHO intake of athletes with severe symptoms (65 ± 25 g.h^{-1}) and those with mild to no GIS (69 ± 27 g.h^{-1}) (Pfeiffer, Stellingwerff, Hodgson, Randell, Pöttgen, Res & Jeukendrup., 2012) provides evidence of the inter-athlete variability in GIS. Given the conflicting findings and the weaknesses associated with observational studies, it is difficult to get a true picture of what elements of the diet may be related to GIS prevalence or severity during ultra-endurance competition.

A series of controlled trials have explored the impact of CHO ingestion on GIS and biological markers of gut damage and permeability in race or laboratory conditions, with as yet inconclusive results. Firstly, in a unique multi-study research project, the incidence of GIS during a 16 km race was variable, but the symptom profile was similar across studies (Pfeiffer et al., 2009). In this multi-component study, authors assessed the impact of ingesting a multi-transportable CHO gel at different rates (study 1, glucose and fructose at 1 g or 1.4 $g.min^{-1}$) and using different types of CHO gels at a high rate (study 2, 1.4 $g.min^{-1}$ of glucose or glucose and fructose). The glucose and fructose gel (high rate) in study 1, was directly comparable to the product (type and volume) used in study 2. In both studies, upper abdominal cramps (1.12 and 1.27) and diarrhea (0.09 and 0.13) had the highest and lowest symptom severity, respectively. However, considerably more runners (23% vs 12%) experienced serious GIS in study 2, compared to study 1. They attributed these differences to individual variations in GI tolerance as they observed that history of GIS was strongly correlated to upper (r = 0.70 to 0.89, p <0.001) and lower (r = 0.46 to 0.90, p <0.001) GIS in both studies.

A smaller laboratory based study, consisting of just seven participants running in the heat (30 ^{o}C) for 60 minutes observed an increase in intestinal–fatty acid binding protein (I-FABP) (524.80 ± 381.25 vs 261.74 ± 160.27 $pg.ml^{-1,}$ p = 0.003) after consuming a single CHO gel (equating to CHO at a rate of 27 $g.hr^{-1}$) but not placebo (consisting of 40 ml water) (Sessions et al., 2016). Intestinal fatty acid-binding protein is regarded as an effective biomarker of gut damage due to its high tissue specificity and its rapid release into the circulation resulting from intestinal injury (Funaoka, Kanda, & Fujii, 2010). While this provides some evidence that CHO intake was associated with damage to the GI tract and intestinal permeability, it is unclear if this translated into GIS symptoms for the participants. Furthermore, failure to record the volume of water consumed in either trial negates firm conclusions as to whether CHO intake alone influenced these markers, given that low fluid intakes are thought to be synonymous with GIS (Stuempfle et al., 2013).

A larger, more robust protocol that assessed the impact of fluid intake with or without CHO, on GI damage and GIS reported interesting findings (Lambert et al., 2008). Primary findings indicated that GI permeability did not increase above baseline during the CHO (in a 4% solution) or placebo (sweetened water) trials. Furthermore, there were no differences in GIS of heartburn, nausea, urge to defecate or abdominal cramps between rest and placebo or glucose solution. Instead, during their double-blinded crossover study, GI permeability was increased when fluid was withheld during a 60-minute run in temperate conditions (24.4 ^{o}C). Suggesting that hydration status may be more influential to GI dysfunction than the composition of fluids, however, GI permeability did not translate into increased GIS severity. The absence of self-reported GIS, despite evidence of GI damage may indicate that the intensity and/or duration of activity were below the threshold for inducing symptoms (Pfeiffer et al., 2012; Pugh et al., 2017).

A relatively new development is the concept of GT to improve tolerance to food and reduce GIS. Gastrointestinal training has been purported to improve tolerance to recommended rates of CHO during both submaximal steady state running and self-paced treadmill running (Costa, et al., 2017; Miall et al., 2017). Specifically, two weeks GT using either a CHO supplement (CHO-S) or a CHO rich food (CHO-F) (both providing 3 x 30 g CHO during a 60 minute training run) reduced GIS between 44 and 49% while ingesting an equivalent volume of CHO-S, during a prolonged running protocol (2 hr at 60% VO_{2max} + 1 hr TT), compared to placebo (Costa, et al., 2017; Miall et al., 2017). This improvement was coupled with reductions in malabsorption and increases in glucose availability, albeit to a lesser extent in the CHO-F group. Consequently, Costa, et al. (2017) highlighted that specificity of CHO ingestion is key to maximise the benefits associated with GT and subsequent performance i.e. training with foods and supplements that runners intend to use during competition. Therefore, the ingestion of CHOs during training comparable to the planned competition nutrition has the potential to reduce GIS and promote nutritional intake during competition.

2.5.3.1 Mechanisms Implicated in the Development of Gastrointestinal Symptoms

The aetiology of GIS has been described as multi-factorial, with complex pathophysiology processes that occur in response to exercise (Miall, Khoo, Rauch, Snipe, Camões-Costa, Gibson, & Costa, 2017). These processes are part of the normal physiological response to exercise, but they result in compromised GI function and integrity, therefore it has been referred to as ‘exercise-induced GI syndrome’ (Costa, et al., 2017). A recent systematic review provided a schematic representation of two functional pathways proposed to contribute to the development of GIS (i) circulatory-gastrointestinal and (ii) neuroendocrine-gastrointestinal pathway (Figure 2.5) (Costa, et al., 2017), which may aid the interpretation of the earlier associations between nutritional intake and GIS. In addition, differences in the symptom profiles between sporting disciplines, point towards a mechanical component to the development of GIS. In runners, repetitive impact is thought to damage the lining of the GI tract in runners, whereas the symptoms experienced by cyclists have been attributed to the pressure on the abdomen while in an aerodynamic position (De Oliveira et al., 2014). The higher risk of GIS in female athletes could also suggest a hormonal mechanism, although this is not yet understood (Ter Steege, Van Der Palen, & Kolkman, 2008).

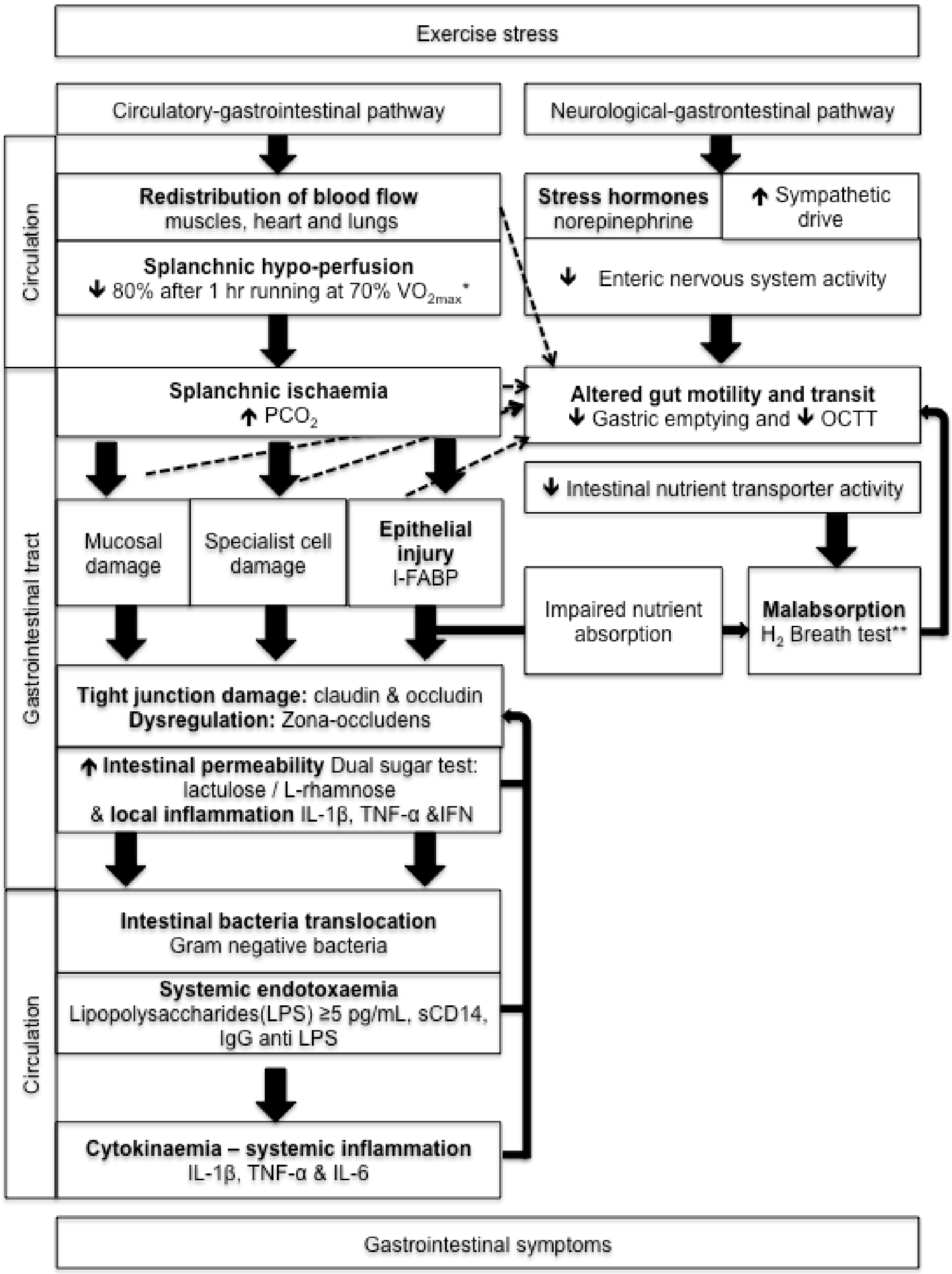


Figure 2.5. Schematic representation of the pathways that contribute to the development of GIS (Costa, et al., 2017) adapted to include known biological markers that measure physiological changes along the pathway. IL- 1β =interleukin 1β, IL-6 = interleukin 6, TNF-α = tumour necrosis factor-alpha, INF = interferon, OCTT *Rehrer, Smets, Reynaert, Goes, and De Meirleir (2001), **Rise in H_2 of ≥10 ppm above baseline (Bate, Irving, Barrett and Gibson, 2010).

The combined effects of the splanchnic shunt (circulatory pathway) and alterations to the enteric nervous system (neuroendocrine pathway) during exercise lead to a series of biological and physiological changes that disrupt GI function and compromise the integrity of the small intestine (Costa, et al., 2017). Firstly, a reduction in blood flow to the gut of ~80% observed during 60 minutes of cycling at 70% VO_{2max} (Rehrer et al., 2001), appears to be a key circulatory factor in the development of GIS. A full review of the cardiovascular adjustments to exercise can be found in the seminal work completed by Rowell (1974). Changes in splanchnic blood flow result in a reduction in gastric CO_2 clearance, which is thought to provide evidence of hypo-perfusion to the stomach and small intestine, along with splanchnic ischeamia (Costa, et al., 2017; Van Wijck et al., 2012; Wijck, Lenaerts, Loon, Peters, Buurman, & Dejong, 2011). Similarly, increases in I-FABP, measured 20 minutes after a 60-minute treadmill run, provide evidence of GI permeability. Although, the increase in I-FABP was significant when runners consumed CHO (semi-solid 27 g), but not a water-based placebo (40 ml), which the authors attributed to elevated intestinal wall damage in the presence of CHO (Sessions et al., 2016). However, failure to observe a significant increase in I-FABP in the placebo trial, may be due to the short half-life (~11 min) (Wijck et al., 2011) rather than the absence of a statistically meaningful increase, given the 20-minute delay in obtaining measurements.

Since reduced splanchnic blood flow is implicated in the development of intestinal ischemia, it is logical that factors capable of amplifying the shift in blood flow would further increase the risk of developing GIS, or the symptom severity. Competition for blood volume between the gut and skin increases during exercise in the heat (Wendt, Van Loon, & Lichtenbelt, 2007). Furthermore, exercise which causes large sweat losses are likely to exhasibate symptoms (Van Nieuwenhoven, Vriens, Brummer, & Brouns, 2000), especially, during races with fewer opportunities to consume fluid (i.e. self-sufficient races in remote locations). As expected, GIS incidence was higher when competing in hot climates (Gill et al., 2015), and more prolonged or intense activities (Pfeiffer et al., 2012; Pugh, Impey, Doran, Fleming, Morton, & Close, 2017). Simiarly, a significant increase in nausea (mean 0.15 vs 0.95, $p = 0.008$) and epigastric cramps (0.40 vs 0.70, $p = 0.049$) was observed during exercise in a dehydrated state (Van Nieuwenhoven, Vriens, Brummer, & Brouns, 2000). Although, there is evidence of inter-individual variability in GIS, with hydration having little impact on the symptoms profile of individual athletes.

Increases in GI permeability during exercise are accompanied by localised and systemic responses including release of inflammatory cytokines (interleukin 1β, interleukin 6, tumour necrosis factor-alpha, interferon) and endotoxins (lipopolysaccharide) (Figure 2.5), which have been detected during an Ironman triathlon (Jeukendrup et al., 1999). Despite evidence that exercise induced hypoperfusion is associated with GI permeability and inflammatory and endotoxin responses, GIS are not always present when these biomarkers are elevated (Karhu, et al., 2017). An inverse relationship between I-FABP and GIS was observed during a prolonged GT study that involved 2 hr of running at 60% VO_{2max} followed by a 60-minute time trial (Costa, et al., 2017). These findings indicate that GI injury, and permeability may not be the main cause of GIS. Instead Costa, et al. (2017) proposed that the presence of GIS may have been related to motility mechanisms.

Delays in the rate of gastric emptying (GE) and oro-cecal transit time (OCTT), induced by exercise have been implicated in the development of upper GIS (neuroendocrine pathway, Figure 2.5), including belching, urge to regurgitate and regurgitation (Costa, et al., 2017), however motility changes are not consistent across sporting disciplines (Van, Brouns, & Brummer, 1999; Van Nieuwenhoven, Brouns, & Brummer, 2004; Van Nieuwenhoven et al., 2000). In well-trained orienteers, running at 70% VO_{2max} did not alter GE time, after a standardised meal

(Strid, Simrén, Störsrud, Stotzer, & Sadik, 2011). While this provides some insight into the impact of exercise on GE during distance running (100 minutes), findings are unlikely to reflect GE rates during ultra-endurance competition. There is an inverse relationship between exercise duration and the rate of GE (Horner, Schubert, Desbrow, Byrne & King, 2015), indicating that GE is more likely to be delayed during ultra-endurance events.

In cyclists without a history of GIS, no changes in GE or OCTT were observed during exercise compared to rest (Van et al., 1999). A similar result was seen for GE and OCTT in long distance cyclists with a history of GIS, however, OCTT was delayed in symptomatic runners (Van Nieuwenhoven et al., 2004). This may indicate that motility disturbances are influenced by the mode of activity. In the latter study, authors compared the GIS experienced by cyclists during two trials. Despite similar OCTT between rest and exercise during both trials, they observed significantly more episodes of reflux in the cyclists with a past history of symptoms. This suggests that past history of GIS is more influential to symptom development than GE and OCTT.

Interestingly, exercise-induced GIS (nausea and epigastric cramps) were observed in previously asymptomatic cyclists while exercising in a dehydrated state (pre exercise BM loss of 3% in a sauna). This was despite consuming the same volume of the CHO solution as when they were in a euhydrated state (Van Nieuwenhoven et al., 2000). These symptoms were coupled with a statistically significant delay in GE (p = 0.021) and a non-significant trend for increased OCTT. This points to the mediating effect of hydration status on exercise-induced motility disturbances (particularly GE) and subsequent symptoms of nausea. Given the prolonged nature of ultra-endurance events and the logistical challenges associated with consuming sufficient fluids to prevent dehydration, delayed GE is likely to be a potential mechanism for GIS during ultra-endurance competition.

Current nutritional recommendations for activities lasting >4 hrs emphasise the importance of appropriate fluid and CHO intake for optimum hydration (McDermott, et al., 2017) and fuel availability (Thomas, et al., 2016) (Section 2.3.2.2). These recommendations are purported to reflect the volume of fluid (400-600 ml) in the stomach for optimum GE and CHO concentration to facilitate absorption, respectively. In contrast, ultra-endurance athletes have been observed to consume food of mixed macronutrient profile (McCubbin Cox & Board, 2016), which may also influence the GE for these athletes. A recent meta-analysis outlining the major contributing factors for GE, concluding that greater volume of food and fluids and higher beverage osmolality delay GE (Horner, et al., 2015). In contrast, the influence of macronutrient content during exercise is not yet understood, however GE is likely to be delayed by high fat intake, given observations in resting conditions (Stacher, et al., 1991). The relationship between these variables and GE may go some way to explaining the aforementioned associations between GIS and CHO volume (Pfeiffer, et al., 2012) (Section 2.5.3).

A recent study documented that 68% of runners suffered CHO malabsorption during prolonged exercise and this was moderately correlated with gut discomfort ($r = 0.425$, $p = 0.034$) and upper GIS ($r = 0.402$, $p = 0.047$) (Costa, et al., 2017). Malabsorption (Figure 2.5) that results in nutrients progressing to the ileum is proposed to provide a feedback mechanism that can impair GI motility (Shin, Ingram, McGill, & Poppitt, 2013). Energy-containing nutrients in the terminal section of the small intestine are thought to provide signals that have enhanced fullness and reduced subsequent nutritional intake. This mechanism has been termed the ‘ileal break’ and could partly explain the suboptimal nutritional intake of ultra-endurance athletes. Although, it is worth noting that the level of malabsorption and GIS can be improved by GT with specific CHO sources (Section 2.5.3).

2.5.3.2 Tools to Quantify the Incidence and Severity of Gastrointestinal Symptoms

The range of GIS quantified during exercise often varies between studies (*n* = 8-19), with the individual number of symptoms categorised as upper (*n* = 4-8), lower (*n* = 3-7) and systemic (*n* = 0-5) symptoms, unique to the specific research study (Costa et al., 2016; Jeukendrup et al., 1999; Pfeiffer et al., 2012; Pugh, Fearn, Morton & Close, 2017; Rehrer, et al., 1992; Ter Steege, Van Der Palen, & Kolkman, 2008). One particular study investigated the prevalence of GIS using just four symptoms; namely nausea, vomiting, abdominal cramps and diarrhoea, and therefore has little comparability with other more diverse explorations of symptom prevalence (Stuempfle, Hoffman, & Hew-Butler, 2013). Moreover, differences in the number of items between tools could in part explain the variability in GIS prevalence in similar races (60 - 96% in 161 km foot race, Stuempfle & Hoffman, 2015; Stuempfle et al., 2013).

Another source of variability, independent of the athlete and the race environment is the method employed to classify the severity of GIS. Some athletes have been required to rate GIS on a Likert-style scale (0-9 or 0-10) with the midpoint indicating the threshold for severe symptoms (Jeukendrup et al., 1999; Pfeiffer et al., 2012; & Ter Steege et al., 2008), while others have recorded GIS on a visual analogue scale with severity assigned based on the incidence of symptoms (i.e. 1 = low, 2-3 moderate and 4≥ high) (Costa et al., 2016). In contrast, Ter Steege et al., (2008) expected athletes to self-rate the severity of their GIS by selecting from four categories; ‘hardly any complaints, ‘moderate complaints’, ‘sever complaints’ and ‘very severe complaints’. In isolation, these arbitrary rating scales do not consider the implications of individual symptoms on athletic performance or the adequacy of the athlete’s nutritional intake. By definition, ‘vomiting’ is likely to have a negative impact on exercise performance (and nutritional intake) independent of symptom severity, whereas ‘flatulence’ is unlikely to compromise these outcome measures in the same way. As such, the symptom profile of an athlete needs to be interpreted according to the context of the race and the athlete’s perception of their individual race performance.

A number of GIS tools have been evaluated for use in a range of countries, but mainly for patient groups with existing GI disorders, such as dyspepsia or gastroesophogeal reflux disease (Bovenschen, Janssen, van Oijen, Laheij, van Rossum, & Jansen, 2006; Kulich, et al., 2008; Revicki, Wood, Wiklund & Crawley, 1998; & Spiegel, et al., 2014). These tools may be considered superior to other instruments, as they have been rigorously assessed for comprehension, with the intended population group, and assessed for validity and reliability (internal consistency and test-retest reliability) using psychometric tests. Both the GIS scale (Speigel, et al., 2014) and the GIS rating scale (Revicki, et al., 1998; & Kulich, et al., 2008) have been deemed to have acceptable validity, quantified by correlations (threshold >0.3 moderate, >0.6 strong, p <0.05) between GIS tools and legacy instruments (such as the short form health survey), in the absence of a suitable criterion measure for GIS. Nonetheless, not all of the symptoms have met the criteria set for validity in all population groups, casting doubt on the appropriateness of the instruments content. Furthermore, the internal consistency reliability and the test-retest reliability have been variable for specific aspects of individual tools (internal: cronbachs α 0.43 to 0.87, test-retest: intraclass correlation coefficient 0.36-0.75, Kulich, et al., 2008). However, it is possible that the absence of acceptable test-retest reliability (>0.70) could reflect the transient nature of GIS, rather than the stability of the instrument.

These tools are less commonly used to assess the incidence and severity of GIS in athletic populations. This possibly reflects limitations in the comprehensiveness of existing validated tools, for assessing the full range of symptoms typically experienced by distance runners (Ter Steege, Palen & Kolman, 2008) and ultra-endurance athletes (Stuempfle, Hoffman & Butler, 2013). Notably, the disease-specific instrument entitled the 'GIS rating scale', used by Pugh, Fearn, Morton, & Close, (2017) to assess the GIS of athletes from a range of sports (including ultramarathon), failed to assess the incidence and severity of vomiting. This is despite 22% of runners experiencing this symptom during a 161 km ultramarathon (Stuempfle, Hoffman & Butler, 2013). Therefore, future studies should use a tool capable of quantifying the full range of GIS, anticipated during prolonged exercise.

In summary, the potential for inadequate or inappropriate nutritional intake to have a detrimental effect on ultra-endurance performance is clearly evident. Optimal nutritional intake is required to stimulate training adaptations and changes to body composition that are favourable to performance. Assuming appropriate training adaptations and body composition are achieved, suboptimal CHO loading prior to an ultra-endurance event or low rates of CHO ingestion during competition may impair performance. During prolonged submaximal activity, inadequate CHO availability and glycogen depletion, results in fatigue and impaired performance. Potential reasons for the considerable energy deficits observed in Section 2.4 include inadequate nutritional knowledge, GIS and social and environmental factors, however, research is needed to confirm this. Furthermore, the limited number of ultra-endurance intervention studies exploring the impact of different nutritional strategies on performance in this domain suggests that further research is required to identify alternative strategies to improve nutritional intake and enhance performance. Gut training, combined with a high CHO diet has the potential to reduce GIS and allow athletes to better meet the recommended CHO intake. While a short term HFLC diet that is capable of increasing fat oxidation has the potential to spare glycogen and enhance performance in ultra-endurance competition. Due to the prolonged nature of an ultra-endurance race, the limited glycogen storage capacity and the challenges to optimum nutritional intake (Section 2.5) a single component nutrition intervention is unlikely to enable said athletes to optimise their performance. As such the aims of this thesis were:

1. To assess the level of nutritional knowledge of ultra-endurance athletes and explore differences in knowledge between sub-groups of the population (Chapter 3, study 1).
2. To explore the relationship between knowledge and nutritional intake during training and competition (Chapter 3, study 1).
3. To identify the main factors that influence the food choices of ultra-endurance athletes during training and competition (Chapter 3, study 2).
4. To establish whether GT combined with a HFLC diet can improve ultra-endurance performance compared to GT and a LFHC diet (Chapter 4, study 3).
5. To investigate whether a GT programme can improve GI tolerance and enable ultra-endurance athletes to meet the CHO recommendations for during competition (Chapter 4, study 3).

6. Finally, to explore the food choices of ultra-endurance runners, during a 56 km race (Chapter 5, study 4).

Chapter 3: Factors Influencing the Nutritional Intake of Ultra-endurance Athletes: Knowledge and Motives

3.1 Study 1: Sports Nutrition Knowledge and Intake of Ultra-Endurance Athletes

3.2 Introduction

It is well established that ultra-endurance athletes, competing in single day events, fail to achieve energy balance during competition. Furthermore, CHO intake is often below recommendations for such prolonged events (Section 2.4.3). The implications of suboptimal nutrition and hydration strategies during ultra-endurance events include; glycogen depletion, hypoglycaemia (Clemente-Suarez, 2015), dehydration and EAH (Knechtle, 2013), which have been associated with impaired performance. In addition, inadequate intake can have negative health consequences, with varying degrees of severity. Chronic energy deficits, combined with nutrient poor food choices, may result in nutrient deficiencies, disturbances to bone, menstrual and cardiovascular health or chronic fatigue (Mountjoy et al., 2014).

More recently, it has been observed that bone metabolism can be impaired by just five days of reduced energy availability in both active and sedentary females (Papageorgiou, Dolan, Elliott-Sale & Sale, 2017). In addition, inappropriate fluid intake, acompanied with EAH can be asymptomatic or present with neurological symptoms such as dizziness and confusion, which can be confused with signs of dehydration (Hoffman et al., 2013). Failure to correctly recognise the symptoms of EAH has led to a number of fatalities (Hew-Butler et al., 2015; and Rosner & Kirven, 2007). This empasises the importance of appropriate nutritional intake, especially given that recent reports have indicated that EAH affects between 4.6% and 51.0% (Costa et al., 2013; Hoffman et al., 2013) of ultra-endurance runners.

Nutritional education programmes, may help to improve the dietary intake of ultra-endurance athletes and mitigate some of the risks associated with inappropriate nutrition and hydration strategies. Earlier studies indicate that there is a significant relationship between nutrition knowledge and diet quality, albeit weak to moderate (Section 2.5.1.2). However, no studies to date have explored the adequacy of ultra-endurance athletes' nutritional knowledge or the relationship with their nutritional intake, possibly due to the absence of an appropriate knowledge questionnaire. Therefore, this study aimed to develop a valid and reliable tool, prior to assessing the level of sport-specific nutrition knowledge of ultra-endurance athletes and exploring differences in knowledge between sub-groups of the population. Based on existing literature, it was hypothesised that there would be no significant differences in nutrition knowledge between sub-groups of the population, in relation to gender (Trakman, et al., 2016) and sporting discipline (Jessri et al., 2010). A secondary aim was to assess the relationship between nutrition knowledge and ultra-endurance athletes' nutritional intake for competition. It was also hypothesised that there would be a negative relationship between nutritional knowledge and energy and CHO deficits, meaning higher knowledge would be associated with lower energy and CHO deficits.

3.3 Method and Results

This study was conducted in two distinct phases. Phase 1 was the development and assessment of the validity and reliability of a new questionnaire for assessing sport and general nutrition knowledge among ultra-endurance athletes. The second phase assessed the internal consistency of the questionnaire and determined the level of nutrition knowledge of a group of experienced ultra-endurance athletes.

3.3.1 Methods Phase 1: Adaptation of a Sport Nutrition Knowledge Questionnaire

3.3.1.1 Participants

Three groups with varying levels of sports nutrition knowledge were recruited to assess the construct validity and test-retest reliability of the adapted questionnaire after providing informed consent electronically. These included experts from the Sports and Exercise Nutrition register (SENr; n = 10) who had formal sports nutrition training (albeit, their experience of working with ultra-endurance athletes and guidelines was not recorded), Registered Dietitians (RD; n = 10) with formal nutrition training for the general population, and individuals who had no nutrition education (GenP; n = 13). The departmental research ethics committee approved this study.

3.3.1.2 Procedures

Zinn and colleagues (2005) sports nutrition knowledge questionnaire was adapted for use with ultra-endurance athletes. These authors provided evidence for the content validity, construct validity and test-retest reliability of the original questionnaire with New Zealand premier rugby players. The questionnaire was amended, using current literature relating to prolonged endurance research and to reflect UK nutrition products. In brief, fluid questions were amended to reflect recommendations for prolonged physical activity (Sawka et al., 2007) and questions associated with strength and power activities were removed. The structure of the questions and the response options were adapted to enhance the clarity and accuracy of the questionnaire. As an example, for questions relating to the level of protein contained in specific food items the number of responses was increased from two to three, with the addition of ‘medium’ to the ‘low’ and ‘high’ responses available in the original questionnaire. The amended questionnaire (ULTRA-Q) included 76 questions (appendix 1) covering the same five themes as the original questionnaire: nutrients (*n* = 37), fluid (*n* = 8), recovery (*n* = 11), body composition (*n* = 12) and supplements (*n* = 8). Subsequently, a panel of four independent RD's who had accredited post-graduate sport nutrition training, reviewed the ULTRA-Q. Via email, they provided feedback on the clarity of the questions and the suitability of the content for ultra-endurance athletes.

After replacing and amending some questions to suit the ultra-endurance domain, the panel endorsed the content validity of the questionnaire. The ULTRA-Q was then circulated electronically to the three groups for pilot testing. The purpose of the pilot testing was to assess the construct validity and test-retest reliability of the questionnaire. To facilitate this, each group completed the questionnaire on two occasions, separated by a minimum of 14 days. This period was chosen to replicate the method used in the original nutrition knowledge questionnaire design (Zinn, Schofield and Wall., 2005), which is purported to reflect a time sufficient enough for participants to forget their initial response, but short enough to minimise a change in knowledge base. Electronic questionnaires were chosen for convenience, to reach as many participants as possible, and for their ability to generate comparable data to pencil-and-paper questionnaires (Lonsdale, Hodge and Rose, 2006). To improve the clarity of the questionnaire, each group was also allowed to comment on their comprehension of individual questions and provide suggestions where necessary.

3.3.1.3 Data analysis

The data was screened for normality prior to the main statistical analysis. Skewness and kurtosis values of <2.0 and <5.0 respectively were considered to indicate reasonable normality (Tabachnick & Fidell, 2007). Multivariate analysis of variance (MANOVA) was used to compare the total nutrition score and the five nutrition theme scores between groups. Pillai's Trace statistics were the MANOVA statistics of choice, and Scheffe's post hoc analysis was used due to the relatively small sample size and uneven participant numbers (Tabachnick and Fidell, 2007). A statistically significant difference in the knowledge scores (total and nutrition themes) of the three groups was seen to provide evidence for the construct validity of the questionnaire (Litwin, 1995). An intra-class correlation coefficient was computed for each of the nutrition themes to assess for test-retest reliability (Weir, 2005). A value greater than 0.7 was set as the threshold for evidence of adequate reliability (Mitchell and Jolley, 2001). All data was analysed using IBM© SPSS© (version 22) with a significance value set to p = 0.05 for all tests unless otherwise specified. In relation the MANOVA statistics, partial eta squared (ηp^2) was computed with 0.10, 0.25 and 0.50 signifying small medium and large effect sizes respectively (Cohen, 1965).

3.3.2 Results Phase 1: Reliability and Validity of the Sports Nutrition Knowledge Questionnaire

The ULTRA-Q was completed by all participants initially and repeated by 29 (87.9%) participants after the 14-day test-retest period. On the two occasions, skewness and kurtosis values for the total score and themes ranged from -1.35 to 0.46 and -1.52 to 2.09 respectively, indicating "reasonable" normality (Tabachnick & Fidell, 2007). There was a significant difference between groups for total nutrition knowledge scores, F (10, 54) = 9.86, p = <0.001, Pillai's Trace = 1.29, η_p^2 = 0.65 (Figure 3.1). Table 3.1 contains the results of the Scheffé's post hoc tests, which were used to compare SENr, RD, and GenP groups on their nutrition knowledge scores. The SENr and RD groups scored significantly higher for nutrients, recovery, and total nutrition knowledge (Table 3.1). SENr scored significantly higher than RD and GenP groups for fluids and supplements knowledge. RD's were significantly higher than the GenP group for body composition knowledge.

In summary, the above results provided evidence for the construct validity of the questionnaire by showing that the SENr and RD groups generally scored higher than the GenP group. In terms of test-retest reliability, the intra-class correlation coefficients for the five nutrition themes were as follows: nutrients (0.95), fluid (0.88), recovery (0.83), body composition (0.85), and supplements (0.75). As all values were above the recommended 0.70 (Weir, 2005), this provided evidence for the test-retest reliability of the questionnaire. Finally, during the pilot testing, the SENr group suggested that contextual information could be added to the ULTRA-Q to aid in the comprehension of individual questions.

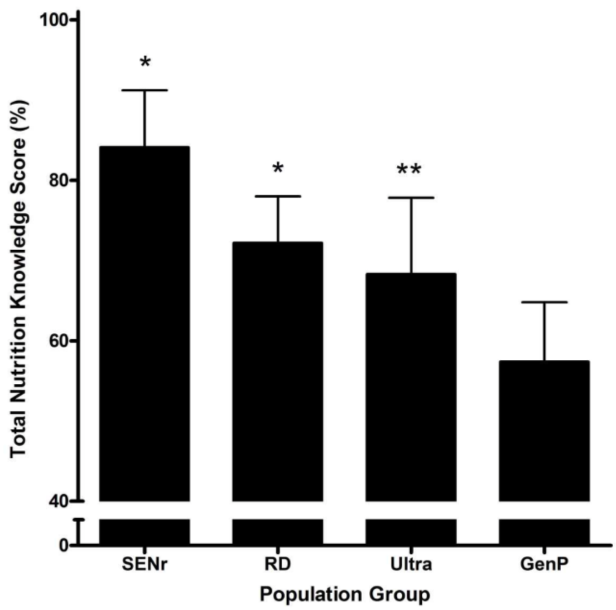


Figure 3.1 Nutrition knowledge of participants from phase 1 (SENr, RD and GenP) and phase 2 (ultra-endurance athletes). *SENr and RD had significantly higher knowledge than GenP, **Ultra-endurance athletes scored significantly higher than GenP (p <0.05).

Table 3.1. Nutrition knowledge sub-group analysis using Scheffe's post hoc multiple comparisons test.

Section	SENr %	RD %	GenP %	Comparison	Mean difference %	Significance*
All	84.1 ± 7.1	76.3 ± 5.6	57.4 ± 7.4	SENr – GenP	26.7	<0.001
				RD - GenP	18.9	<0.001
Nutrients	88.9 ± 4.3	87.8 ± 6.9	60.9 ± 9.9	SENr – GenP	28.0	<0.001
				RD - GenP	26.9	<0.001
Fluid	76.3 ± 1.6	41.3 ± 13.2	49.0 ± 13.2	SENr – RD	35.0	<0.001
				SENr – GenP	27.3	0.002
Recovery	92.7 ± 11.2	89.1 ± 8.4	61.5 ± 16.7	SENr – GenP	31.2	<0.001
				RD – GenP	27.6	<0.001
Body composition	76.7 ± 21.1	81.7 ± 12.3	62.8 ± 13.9	RD – GenP	18.9	0.031
Supplements	68.8 ± 19.8	32.5 ± 36.9	35.6 ± 31.4	SENr – RD	36.3	0.041
				SENr - GenP	33.2	0.047

* This table includes the group comparisons that resulted in a significant difference only. All other group comparisons failed to reach statistical significance.

3.3.3 Methods Phase 2: Assessing Ultra-Endurance Athletes' Sports Nutrition Knowledge

3.3.3.1 Participants

Male (*n* = 74) and female (*n* = 27) ultra-endurance athletes, aged 41.7 ± 8.1 and 39.0 ± 9.6 years respectively, were recruited via a UK based, custom designed research website to complete the finalised version of the sports nutrition knowledge questionnaire. Athletes who registered their interest through the website were sent a link to the knowledge questionnaire, which was conducted through Bristol Online Survey© software (Bristol, England, 2013). Interested athletes, who did not complete the questionnaire, were sent reminder emails at 7 and 14 days after the initial contact to encourage participation in phase 2 of the study. Subsequently, to investigate the relationship between nutrition knowledge and dietary intake, a subsample of 23 athletes agreed to record their nutritional intake and activity levels for four specific days. This represented the 24 hr period prior to an ultra-endurance training session (pre-TRAIN), the day of an ultra-endurance training session (TRAIN), the 24 hr immediately before an ultra-endurance competition (pre-COMP) and the day of an ultra-endurance competition (COMP). Full details of the sample and subsample characteristics are contained in Table 3.2.

3.3.3.2 Procedures

After phase 1, additional contextual information was added to the ULTRA-Q to aid the comprehension of individual questions, as recommend by the SENr group. A further eight questions were also added to the questionnaire to gather demographic data and sources of nutrition knowledge. Subsequently, the ULTRA-Q was completed electronically by a sample of ultra-endurance athletes. Like in phase 1, responses to questions were coded (1 = correct response or 0 = all other responses) for statistical analyses purposes.

The subsample of ultra-endurance athletes who volunteered to record their nutritional intake and activity, completed the first two days of the food and activity diary alongside a training session lasting >4 hr, after providing informed consent. Athletes were subsequently contacted 48 hr before their scheduled race to prompt them to complete the second two days of the food and activity diary. The food element of the diary was adapted from the household measures dietary record used in a large epidemiological study (University of Cambridge, n.d.). Prior to distribution, the amended diary was piloted with 23 undergraduate sports and exercise science students to assess its functionality. The completed diaries were subsequently reviewed to identify any missing data that would be needed for accurate nutritional analysis. As such, appropriate prompts were added to the diary and a brief training video was produced to aid accurate recording. Furthermore, diaries completed by the ultra-endurance athletes were analysed within 48 hours of their receipt, to allow missing data to be requested immediately via email, to minimise the error associated with memory recall (Shim et al., 2014).

The food and activity diaries were analysed using analysis software (Nutritics version 3.7 Professional), by the same Registered Dietitian on two separate occasions. To enhance intra-observer reliability, an energy intake discrepancy of more than 200 kcals was investigated, checking all entries against the completed diary and making appropriate amendments in the analysis software. Energy expenditure was estimated using Harris and Benedict (1919) predictive equation for resting metabolic rate and metabolic equivalents (METS) for the specific activities recorded during the 24 hr period. The METS associated with their race were allocated based on the estimated pace of the athlete using the distance and duration recorded for competition (Ainsworth, et al., 2011).

Table 3.2. Ultra-endurance athlete characteristics.

		All athletes *n* (%)	Sub-sample n (%)
Gender	Male	74 (73.3)	15 (65.2)
	Female	27 (26.7)	8 (24.8)
Age (yrs)	Male	41.7 ± 8.1*	38.5 ± 6.8*
	Female	39.0 ± 9.6*	39.3 ± 11.0*
Discipline	Runner	70 (69.3)	17 (73.9)
	Cyclist	5 (5.0)	-
	Triathlete	21 (20.8)	5 (21.7)
	Adventurer	5 (5.0)	1 (4.3)
Locations	UK only	67 (66.3)	17 (73.9)
	Europe	21 (20.7)	5 (26.1)
	USA and Canada	3 (2.9)	
	Other	10 (9.8)	
Past events (*n*)	1-3	34 (33.7)	6 (26.0)
	4-6	31 (30.7)	6 (26.1)
	7-9	8 (7.9)	2 (8.7)
	≥10	28 (27.7)	9 (39.1)
Training time (h.week^{-1})	≤10	56 (55.4)	13 (56.5)
	11-20	40 (39.6)	9 (39.1)
	>20	3 (3.0)	1 (4.3)
	Missing data	2 (2.0)	-
Nutrition education	None	96 (95.0)	23 (100.0)
	NVQ	2 (2.0)	
	Diploma	1 (1.0)	
	Module	1 (1.0)	
	Undergraduate degree	1 (1.0)	

*Mean ± standard deviation, NVQ = National Vocational Qualification.

3.3.3.3 Data analysis

The same approach adopted in Phase 1 was used to assess the normality of the data from the knowledge questionnaire and the food and activity. The internal consistency reliability of each subscale (five themes) within the knowledge questionnaire was also assessed. A reliability coefficient above 0.60 was deemed to represent adequate internal consistency reliability (Hair Anderson, Tatham, & Black, 2006). Due to the binary nature of responses (i.e., correct or incorrect), internal consistency reliability was assessed via latent variable modelling (Raykov, Dimitrov, and Asparouhov, 2010). To compare the nutrition scores between subgroups (i.e. gender and ultra-endurance disciplines) a series of MANOVA's were conducted. Wilks' Lambda was the MANOVA statistic of choice due to the larger sample size (Tabachnick and Fidell, 2007) and Scheffé's post hoc analysis was completed for its suitability when considering complicated comparisons i.e. comparing some of the disciplines and not others (Wallenstein, Zucker, & Fleiss, 1980).

Nutritional intake for the full day, pre-race meal and consumed during the race were analysed separately to allow comparison to best practice guidelines (Thomas et al., 2016). Total energy intake was compared to total energy expenditure using Wilcoxon's one sample signed rank tests. Similarly CHOs and protein were compared to appropriate nutritional recommendations. The relationship between athletes' nutritional intake and the level of sports nutrition knowledge was explored using multiple Spearman's rank correlations, with Bonferoni correction for the number of comparisons. Effect sizes were estimated using rank biserial correlation (*r*) for the Wilcoxon's one sample signed rank tests. These were interpreted as <0.2 very weak, <0.4 weak, <0.6 moderate, and < 0.8 strong effects respectively (Evans, 1996). In relation the MANOVA statistics, effect sizes were computed as described in phase 1.

3.3.4 Results Phase 2: Nutrition Knowledge of Ultra-Endurance Athletes

3.3.4.1 Knowledge

During phase 2, skewness and kurtosis values ranged from -1.42 to -0.21 and -0.91 to 3.89 respectively, indicating reasonable normality (Tabachnick & Fidell, 2007). The reliability scores for the nutrition themes were as follows: nutrients (0.87), fluids

(0.63), recovery (0.81), body composition (0.70), and supplements (0.87). As all scores were above the 0.60 recommendation for adequate reliability (Hair et al., 2006), this provided evidence for the internal consistency reliability of each subscale of the questionnaire. The total nutrition knowledge score for all ultra-endurance athletes was 68.3 ± 9.5% which was significantly greater than the GenP group and lower than the SENr group (Figure 3.1). Sub-group analysis (Table 3.3) based on gender revealed that the nutrition knowledge of males (67.4 ± 9.6%) and females (70.7 ± 9.3%) did not differ, F (5, 95) = 1.73, p = 0.14, Wilks' Lambda = 0.92, $\eta_p{}^2$= 0.08. Mean nutrition scores for triathletes, cyclists, runners, and adventurers ranged between 65.1 ± 9.4% and 72.4 ± 8.2%. There were no significant differences in nutrition knowledge between runners and triathletes, F (5, 85) = 0.61, p = 0.69, Wilks' Lambda = 0.97, $\eta_p{}^2$ = 0.04, but low response rates in the other disciplines prevented further comparisons.

Only 5% of ultra-endurance athletes possessed a nutrition qualification (Table 3.2), the level of which ranged from National Vocational Qualification (NVQ) to Undergraduate Degree. Despite this, only 7.8% of athletes reported seeking nutrition information from a Registered Dietitian or Nutritionist (Figure 3.2a). Other professionals involved in supporting athletes were only slightly more likely to be reported as a source of information, with 9.8% seeking nutrition advice from coaches and 11.8% from other support team members. Instead, athletes favoured obtaining nutrition information from magazines and other athletes, with the majority of athletes (Figure 3.2b) obtaining their nutrition information from more than one source.

Table 3.3. Nutrition knowledge, percentage of correct responses achieved by ultra-endurance athletes (Mean ± standard deviation).

		Total score %	Nutrients %	Fluid %	Recovery %	Body Composition %	Supplement %
No of questions		76	37	8	11	12	8
All athletes		68.3 ± 9.5	70.8 ± 11.5	58.2 ± 18.6	77.8 ± 15.3	70.1 ± 15.4	51.1 ± 30.6
Gender	Males (n = 74)	67.4 ± 9.6*	70.2 ± 9.3	57.1 ± 19.1	76.4 ± 16.1	67.8 ± 15.8	52.4 ± 30.6
	Females (n = 27)	70.7 ± 9.3*	72.5 ± 12.4	61.1 ± 17.1	81.5 ± 12.7	76.9 ± 12.1	47.7 ± 30.8
Athlete	Runner (n = 70)	69.1 ± 9.7*	71.7 ± 11.7	58.6 ± 17.4	78.7 ± 16.4	71.0 ± 14.8	51.4 ± 31.4
	Cyclist (n = 5)	66.8 ± 6.8	62.2 ± 9.5	57.5 ± 22.7	76.4 ± 8.1	78.3 ± 15.1	67.5 ± 16.8
	Triathlete (n = 21)	65.1 ± 9.4*	68.5 ± 10.3	53.6 ± 21.7	73.6 ± 13.1	66.3 ± 17.7	47.6 ± 32.7
	Adventurer (n = 5)	72.4 ± 8.2	76.8 ± 12.5	72.5 ± 16.3	83.6 ± 13.5	66.7 ± 13.2	45.0 ± 16.8

* Sub-group comparisons for gender and athlete type (between runners and triathletes only) revealed no significant differences between groups (p = 0.14 and 0.69, respectively).

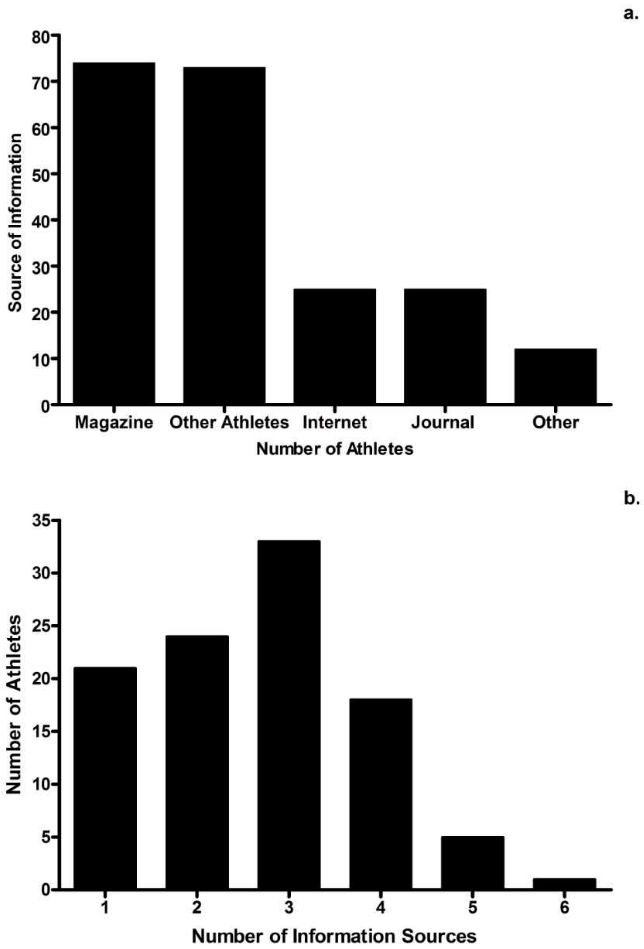


Figure 3.2. Key sources of nutrition information (a) and number of sources of information (b) for ultra-endurance athletes. Other sources providing knowledge to for between 2 and 12% athletes each were; support team, books, coach, advert, health professional, dietitian, trial and error, own knowledge, friend and conference in descending order.

3.3.4.2 Nutritional intake

Sixteen ultra-endurance athletes completed the 24 hr food diaries for Pre-TRAIN and TRAIN, while 21 and 23 ultra-endurance athletes completed the records for Pre-COMP and COMP, respectively. Skewness and Kurtosis values for the food and activity diary data ranged from -0.86 to 1.88 and -1.04 to 7.27 respectively, which was outside the threshold for acceptable normality

(Tabachnick & Fidell, 2007). Total energy intake was significantly below estimated energy expenditure for both TRAIN and COMP, difference -1578.5 kcals $Z = -3.41$, $p = 0.001$, $r = 0.85$ and -3841.0 kcals $Z = -4.20$, $p < 0.001$, $r = 0.88$, respectively (Figure 3.3a). In contrast, the energy intake was significantly greater than expenditure during the Pre-COMP period, difference 392.7, $Z = -3.22$, $p = 0.001$, $r = 0.74$ (Figure 3.3a). The rate of CHO intake during exercise for both TRAIN and COMP was significantly lower than best practice recommendations, difference -71.8 $g.hr^{-1}$ $Z = -3.46$, $p = 0.001$, $r = 0.87$ and -53.5 $g.hr^{-1}$ $Z = -4.07$, $p < 0.001$, $r = 0.85$, respectively. Furthermore, the total CHO intake (relative to BM) was significantly below recommendations for CHO-loading during Pre-TRAIN and Pre-COMP, difference 5.5 $g.kg^{-1}$, $Z = -3.52$, $p < 0.001$, $r = 0.88$ and 2.7 $g.kg^{-1}$, $Z = -2.28$, $p = 0.023$, $r = 0.50$, respectively. In contrast, the total CHO was significantly below the recommendations for activities lasting >4 hr during the TRAIN period, only, 2.9 $g.kg^{-1}$, $Z = -3.41$, $p = 0.001$, $r = 0.85$.

3.3.4.3 Relationship Between Nutritional Knowledge and Intake

Total nutrition knowledge was positively correlated with absolute energy balance during COMP, $r_s = 0.56$, $p = 0.003$, but not relative energy balance, $r_s = 0.48$, $p = 0.022$ when using the Bonferoni corrected *p*-value for the number of days the food diary was kept. There were no further correlations between total nutrition knowledge and energy balance for the other three days. Similarly, there were no correlations between the total volume of CHO consumed or the rate that CHO was ingested during exercise for any of the food records ($p = 0.221$ to 0.471). Furthermore, there were no significant correlations between the nutrition knowledge for any of the five sub-themes and energy balance or the carbohydrate targets (p = 0.025 to 0.491), after a Bonferoni correction for the number of knowledge sub-themes.

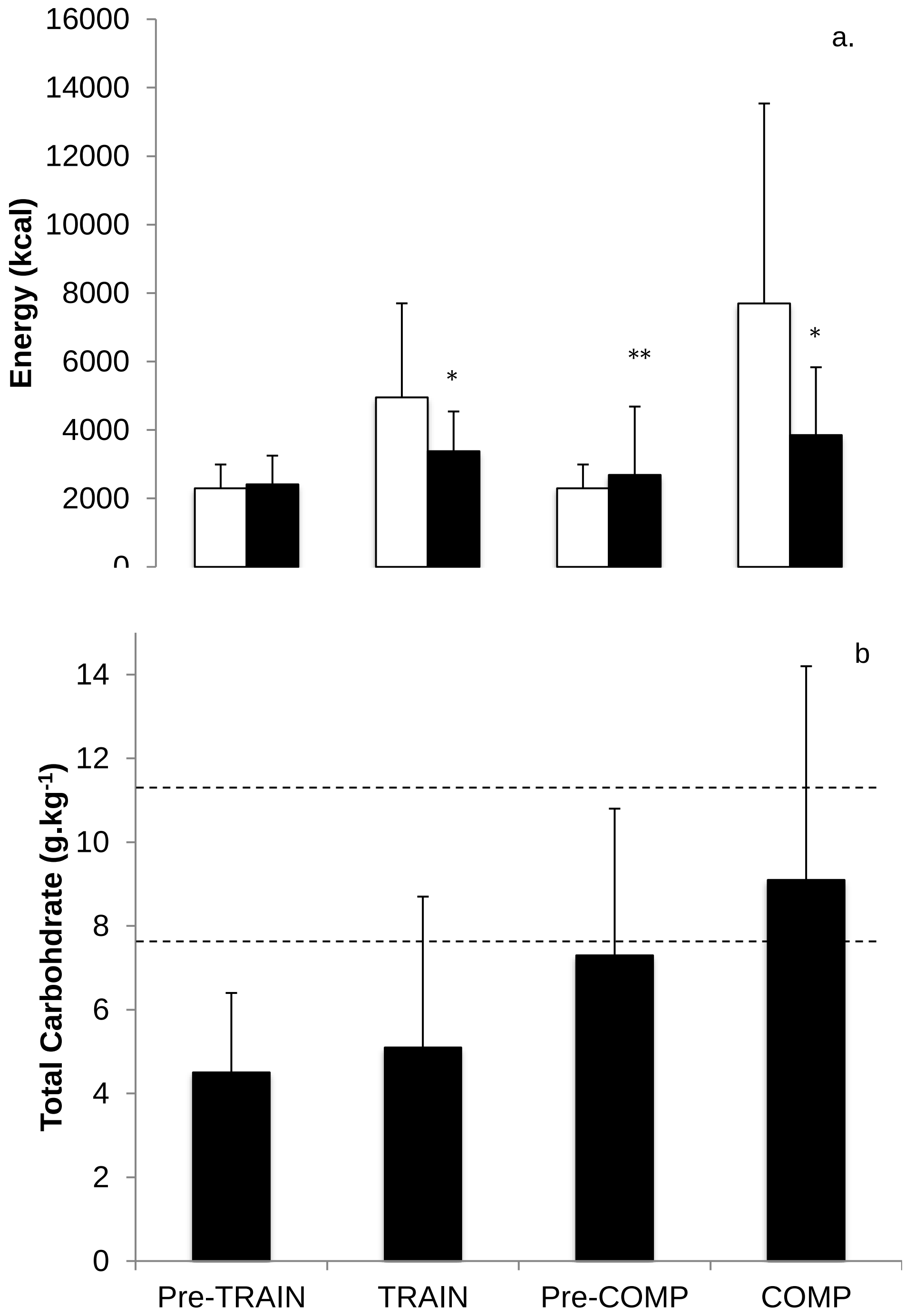


Figure 3.3 Daily energy intake (black) compared to energy expenditure (white) (a) and daily carbohydrate intake, relative to BM (b), lines represent minimum and carbohydrate target for moderate to high intensity exercise lasting >4 hr and maximum target for carbohydrate loading (Burke, et al., 2011). *energy intake significantly below energy expenditure (p <0.01) **energy intake significantly greater than energy expenditure (p = 0.001)

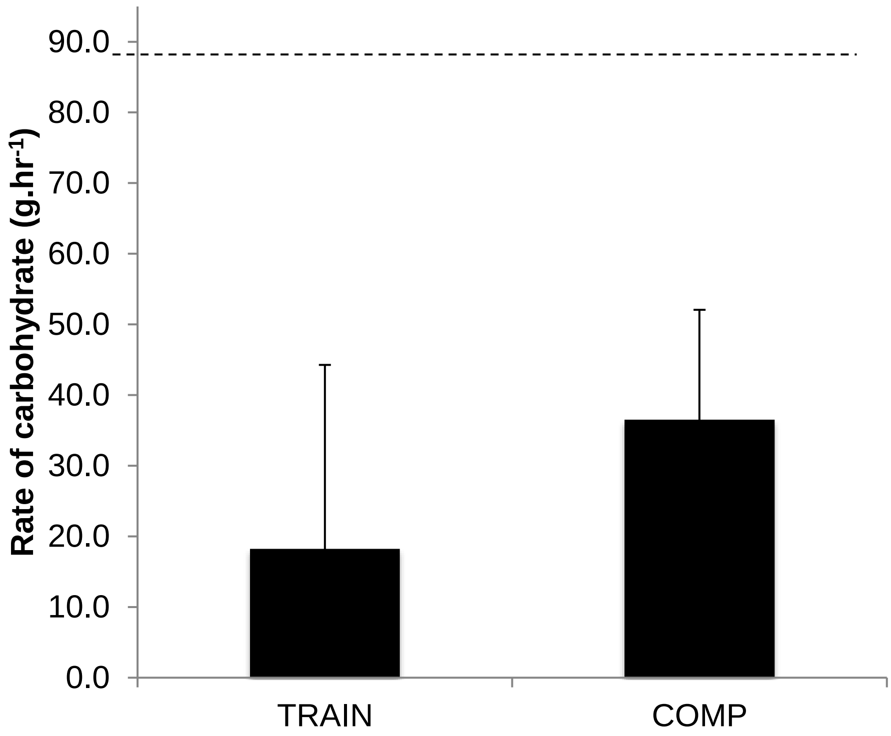


Figure 3.4 Rate of carbohydrate intake during ultra-endurance training and competition. Line represents the recommended rate of carbohydrate intake (Thomas, et al., 2016).

3.4 Discussion

Despite interest in the nutrition knowledge of athletes (Trakman et al., 2016), this is the first study to examine the knowledge of ultra-endurance athletes. Existing nutrition knowledge questionnaires lack specificity for ultra-endurance activities and were deemed unsuitable to assess the knowledge of ultra-endurance athletes. This study therefore employed a two-phase approach to adapt an existing questionnaire and assess the knowledge of ultra-endurance athletes. Across phases 1 and 2, evidence was provided for the content validity, construct validity, test-retest reliability, and internal consistency reliability of the ULTRA-Q. Firstly, a panel of experts provided evidence for the content validity of all items and ensured that the wording of questions was clear. Differences in nutrition knowledge scores between distinct groups (SENr, RD, and GenP) provided evidence for the construct validity of the questionnaire. Intra-class correlation coefficients between time 1 and time 2 scores provided evidence for the test-retest reliability of the questionnaire. The reliability scores for each nutrition theme suggested that the ULTRA-Q had acceptable internal consistency reliability. Together, these findings indicate that the ULTRA-Q is an acceptable tool to assess ultra-endurance athletes' level of sports nutrition knowledge.

Overall, the total sports nutrition knowledge of the ultra-endurance athletes was 68.3 ± 9.5%. Using a similar scoring system, Torres-McGehee, et al. (2012) suggested that a score >75% is required to demonstrate adequate knowledge. This implies that the nutrition knowledge of the ultra-endurance athletes' in the present research was slightly "below par", however, it is not clear whether the difficulty of the questions in their questionnaire was comparable to the current questionnaire. Nevertheless, it appears that ultra-endurance athletes scored ~36% higher than college athletes (Jessri et al., 2010) who completed the original version of the questionnaire (Zinn et al., 2005). It is possible that the superior sports nutrition knowledge of these ultra-endurance athletes may in part be attributed to their older age (males 41.7 years and females 39.0 years) compared to college athletes, as they may have acquired more nutrition knowledge across their lifespan. Wardle, Parmenter & Waller., (2000) observed a similar pattern, with people of middle age (35 - 44 years) scoring higher on nutrition knowledge than people of a younger age (18 - 34 years). The importance of nutrition for ultra-endurance events is obvious therefore these athletes are likely to make more concerted efforts to obtain nutrition information than other players. Compared to previous research, our ultra-endurance athletes scored considerably better than coaches (13.9%) surveyed by Zinn et al. (2006). This was somewhat unexpected given that a recent systematic review purported that coaches generally scored better than athletes on nutrition knowledge (Trakman et al., 2016).

In agreement with the primary hypothesis, sub-group analysis in phase 2 of this study indicated that there was no difference in nutrition knowledge between males and females or between ultra-endurance runners and triathletes. Previous studies exploring differences in nutrition knowledge between sub-groups have been equivocal (Trakman et al., 2016). This is evident, as ten of fifteen studies exploring gender differences reported no significant differences between males and females (Trakman et al., 2016). In contrast, studies by Jessri, et al. (2010) and Arazi and Hosseini (2012), have observed differences in the level of nutrition knowledge between some sub-groups. Firstly, Jessri et al. (2010) reported significantly higher nutrition knowledge for female athletes compared to male athletes, but no differences between sports disciplines (football vs. basketball). Secondly, Arazi and Hosseini (2012) reported significantly higher nutrition knowledge for male collegiate athletes compared to their non-collegiate counterparts of the opposite gender. In contrast, there was no difference in nutrition knowledge between male and female athletes competing at the same level (Arazi and Hosseini, 2012). The differences in the level of nutrition knowledge between genders in these studies may be a reflection of confounding variables such as nutrition education and performance level, rather than gender ‘per se’. As such, future studies using the ULTRA-Q should assess potential differences in nutrition knowledge levels between ultra-endurance athletes who differ on these two variables (i.e. nutrition education and performance level).

The significant energy deficits of the subsample of ultra-endurance athletes during TRAIN and COMP was consistent with previous literature, which casts doubt on the adequacy of the nutrition strategies employed by such athletes. It is widely reported that the considerable demands of ultra-endurance competition result in significant energy deficits for the majority (Armstrong, 2012, Bescoes, et al, 2012, Black, et al, 2012, Enqvist, et al, 2010, Bourrilhon, et al, 2009; and Kruseman, Bucher, Bovard, Kayser, & Bovier 2005) but not all athletes (Rontoyannis, Skoulis and Pavlou, 1989). While our ultra-endurance athletes achieved a positive energy balance during the Pre-COMP period, this was insufficient to counterbalance the subsequent energy deficit. When competition lasts several days, energy deficits accrued can become difficult to reverse even with consecutive days of positive energy balance in the weeks following the event (Knetchel, Enggist and Jehle, 2005). This practice may have implications for energy availability and its associated health risks (Loucks, 2007). Sustained energy deficits that result from a daily energy intake of <30 $kcal.kg^{-1}$ of fat free mass (FFM) are linked with metabolic changes that suppress bone formation and immune function and can have negative effects on cardiovascular health and menstrual function (Mountjoy, et al, 2014).

In addition to significant energy deficits, the observed suboptimal CHO (36.5 ± 16.9[1]) intake during competition was similar to previous studies of recreational ultra-marathon runners (*n* = 213) 32.2 ± 15.2 $g.hr^{-1}$ (Martinez et al., 2017) and (*n* = 6) 35.4 $g.hr^{-1}$ (Clemente-Suárez, 2015). In contrast, substantially greater rates of CHO consumption have been observed in small studies of ultra-endurance triathletes (*n* = 11) 84 ± 18 $g.h^{-1}$ (Barrero, Erola, & Bescós, 2015) and elite ultra-marathon runners (*n* = 3) 71.0 ± 20.0 $g.h^{-1}$ (Stellingwerff, 2016), although there is considerable variability between individual athletes. Low CHO intake during competition may result in early glycogen depletion, fatigue and ultimately impaired performance, although to date it appears that this has not been investigated in ultra-endurance athletes. In contrast to the secondary hypothesis, the current study indicates that the inadequate CHO and negative energy balance (relative to total energy requirements) of the athletes was not a reflection of their nutrition knowledge as there was no relationship between these variables. While nutrition knowledge has been associated with better nutrition practices in the general population and other sporting groups this tends to be modest (Spronk, 2014). Therefore, future studies should seek to explore the factors that impair nutritional intake of ultra-endurance athletes (Chapter 3, study 2).

Another focus of the present research was the sources of nutrition knowledge for ultra-endurance athletes. Despite the low prevalence of nutrition qualifications amongst participants, only 8% of athletes acquired nutrition information from a Registered Dietitian/Nutritionist, compared to 74% from magazines and 73% from other athletes. This fits with previous research showing that athletes favour the media, magazines, parents, coaches, and fellow athletes when obtaining nutritional information/knowledge (Jessri et al., 2010; Shifflett Timm, & Kahanov 2002; Sedek and Yih, 2014). Similar to the current research, Jessri et al. (2010) reported that <1% of athletes ranked a RD in their top three sources of nutrition knowledge. This suggests that nutrition professionals need to engage in promotion activities to raise their profile amongst athletic groups.

Like all studies, this research had a number of limitations, which need to be discussed. Firstly, despite rigorous promotion of the research through social media and race websites, low responses from cyclists and adventurers prevented a comparison of these groups with runners and triathletes. As such, future research should look to obtain a suitable sample size of athletes across each discipline to allow full sub-group comparisons. Secondly, the ULTRA-Q was limited to assessing the level of nutrition knowledge of ultra-endurance athletes and it was not capable of determining whether a particular knowledge level translated into appropriate dietary practices. Future research assessing nutrition knowledge, alongside nutritional intake for ultra-endurance training and competition, are needed to investigate the impact of knowledge on actual dietary practices.

3.5 Conclusion

In summary, the findings from this study provided evidence for the content validity, construct validity, test-retest reliability, and internal consistency reliability of the ULTRA-Q. As such, this questionnaire can be used to assess the nutrition knowledge of ultra-endurance athletes in five domains: nutrients, fluid, recovery, body composition, and supplements. In practical terms, applied practitioners could use the ULTRA-Q to assess baseline knowledge amongst ultra-endurance athletes and tailor their interventions accordingly.

Future studies investigating factors that prevent optimal nutritional intake may further support nutrition practitioners working with ultra-endurance athletes.

3.6 Study 2: Factors Influencing Ultra-Endurance Athletes' Food Choices: An Adapted Food Choice Questionnaire

3.7 Introduction

The superior nutrition knowledge of ultra-endurance athletes compared to the general population in Figure 3.1 suggests that ultra-endurance athletes may be aware of the integral role of nutrition to their athletic performance and health. Despite this, their higher nutrition knowledge was not concomitant with energy balance or CHO intake that meets best practice recommendations for CHO loading or during prolonged exercise (Section 3.3.4.3). In order to improve the dietary intake of ultra-endurance athletes, registered sports nutrition professionals would benefit from understanding the broader factors that influence the food choices of ultra-endurance athletes, during training and competition.

An extensive body of literature has explored the factors that influence food choice in general population groups (Onwezen, Reinders, Verain & Snoek, 2019, Markovina, et al., 2015 & Renner, Sproesser, Strohbach & Schupp, 2012), and to a lesser extent sporting disciplines (Pelly, Burkhart & Dunn, 2018 & Turner-McGrievy, Moore, & Barr-Anderson, 2016). Sensory factors (especially taste), along with price, appear to dominate the food choices of the general population (Onwezen, Reinders, Verain & Snoek, 2019, Markovina, et al., 2015 & Renner, Sproesser, Strohbach & Schupp, 2012), albeit with some variability across European countries and eating environments. In contrast, performance related factors, were most influential to athletes when selecting foods during two Commonwealth Games. At Melbourne (2006), 'nutrition composition' (4.36 ± 0.78) was deemed the most influential performance factor, however this was dominated by 'time of day' (4.20 ± 0.97 compared to 4.05 ± 0.91), during the Dehli (2010) Commonwealth Games. This variability is consistent with observations, that food choices are often situation specific (Furst, et al., 1996). As such, the transferability of these findings to ultra-endurance populations is questionable, given that the questionnaire was completed at the athlete village, which does not reflect the ultra-endurance pre-competition environment.

Notably, across studies, the majority of tools used to explore food choice, were adapted from the food choices questionnaire developed by Steptoe and colleagues (1995), to meet the needs of the population of interest. Despite several revisions, existing surveys lack application to the ultra-endurance context (Section 2.5.2.2). Therefore, this study aimed to develop a valid and reliable food choice questionnaire, prior to assessing the factors that influence the food choices of ultra-endurance athletes. Given the prevalence of GIS and the associated detriments to performance (Section 1.4), it was hypothesised that the avoidance of GIS would achieve the highest importance rating.

3.8 Methods and Results

This study was completed in two phases. In phase 1, an existing tool for exploring the factors influencing the food choices of the general population was adapted for use with ultra-endurance athletes. The revised questionnaire was subsequently assessed for internal consistency and re-test reliability. During phase 2, the adapted questionnaire was completed by a group of experienced ultra-endurance athletes to determine the factors most influential to their food choices for prolonged training and competition.

3.8.1 Methods Phase 1: Adaptation of a Food Choices Questionnaire

3.8.1.1 Participants

Experienced non-professional distance athletes (runners, n = 11 and cyclists, n = 8) from local athletics clubs were recruited to this study, after providing informed consent. All athletes were actively training and competing in single day long distance events (distances ≥26 miles for runners and ≥60 miles for cyclists). This provided recent experience of making food choices for prolonged endurance events, which they used to inform their response during phase 1. The departmental research ethics committee approved this study.

3.8.1.2 Procedures

The food choice questionnaire (FCQ) developed by Steptoe and colleagues (1995) was chosen as the basis of our questionnaire for it's acceptable re-test reliability (r > 0.70) and internal consistency (Cronbachs α 0.72 - 0.86) and the acceptability of the components of the FCQ across 9 European countries (Markovina et al., 2015). The original FCQ contained 36 items, covering nine general factors (or dimensions) namely, health, mood, convenience, sensory appeal, natural content, price, weight control, familiarity and ethical concern, required participants to rate the level of importance of each item. Despite its statistical robustness, the FCQ had been criticised in relation to the comprehensiveness of the conceptual framework and for the adequacy of the 4-point rating scale for detecting meaningful differences in the level of importance of factors influencing food choices (Lindeman and Vaananen, 2000 and Fotopoulos, et al., 2009). In addition, it was evident from a review of the ultra-endurance literature that a number of the existing items lacked ecological validity for the present population and were not applicable for periods of high volume training or competition.

To address these inadequacies, additional items were added in relation to ethical issues, dietary restrictions, such as allergy/intolerance and a series of items considered as important within ultra-endurance research (Bescos, et al., 2012, Hulton, et al., 2010 and Kimber, et al., 2002) or by other athletic groups during their training or competition period (Heaney, et al, 2008, Robins and Hetherington, 2005; and Smart and Bisogni, 2001). This included items relating to GI discomfort and the ease of consumption while training or competing. In addition, the rating scale was extended to a 7-point rating scale (1 = extremely unimportant to 7 = extremely important), which was bipolar in nature to allow a neutral mid-point and to enhance the potential to discriminate between the factors that were regarded as most and least important (Brace, 2008).

The resulting items (n = 84) and factors (n = 13), along with the new rating scale were used to produce the amended FCQ, which was circulated to the distance athletes via email for three purposes (i) to determine the appropriateness of the items allocated to each factor and (ii) to identify the factors with the greatest importance for retention in the final questionnaire (Figure 3.5) and (iii) to assess the internal consistency and test-retest reliability. To facilitate the assessment of the test-retest reliability, the questionnaire was completed a second time by the cyclists and runners (test *n* = 19 and retest *n* = 17), after 17 ± 8 days.

3.8.1.3 Data Analysis

Distance athletes rating scores were screened for normality prior to the main statistical analysis. Skewness (-2.809 to 2.661) and kurtosis (-1.828 to 11.491) values indicated that the data was non-parametric in nature (Curran, West and Finch, 1996). This combined with the small sample size relative to the number of items, indicated that the data did not meet the assumptions for principle component analysis (Pallant, 2016). In the absence of a suitable alternative for this sample, a number of strategies were employed to simulate the key steps of exploratory factor analysis, as described by Williams, Onsman and Brown (2010). Firstly, to replace the scree test for reducing the number of items in the adapted questionnaire (factor extraction), items regarded as unimportant for >50% of athletes were removed. Secondly, to replace the oblique rotational method for assessing whether individual items related to more than one factor Spearman's rank order correlations were computed between all items (*n* = 84), regardless of their assigned dimension.

Finally, as statistical analysis cannot differentiate between causal and chance relationships, items that correlated with items outside of their proposed dimension were reviewed for ecological sense (i.e. a correlation between 'time to prepare' and 'packed in an environmentally friendly way' would be regarded as a chance relationship that was not ecologically sound). During this interpretative process, a strong correlation (r_s ≥0.60, p <0.05, Evans, 1996) that was deemed to be ecologically sound resulted in a change in the classification of that item, unless the original dimension produced a stronger correlation. Furthermore, items that did not produce a significant correlation were considered to be superfluous and therefore removed, unless rated as important by >50% of participants. In which case a new dimension was produced to differentiate items that did not appear to fit their assigned factor, within the conceptual framework.

Subsequently, the refined questionnaire (ULTRA-FCQ) was assessed for internal consistency and test-retest reliability. Internal consistency was assessed using Cronbachs alpha, with $\alpha \geq 0.7$ regarded as the acceptable threshold (Bland and Altman, 1997). To assess for test-retest reliability, an intra-class correlation coefficient was computed for each factor (Weir, 2005). A value greater than 0.7 was set as the threshold for evidence of adequate reliability (Mitchell and Jolley, 2001). All data was analysed using IBM© SPSS© (version 22) with a significance value set to $p = 0.05$ for all tests.

3.8.2 Results Phase 1: Reliability and Validity of the Food Choices Questionnaire

The adapted questionnaire consisted of 13 factors, containing between two and 13 items each. The *median* ± *interquartile range (IQR)* rating scores for each factor ranged from *2.0* ± *3.0 to 6.0* ± *1.0* (Table 3.4). The factors that were rated most important to participants overall were ‘somatic’ and ‘event’ however, subgroup analysis indicated a high degree of variability in the rating score of the ‘somatic’ factors for runners (*5.0* ± *4.0)*. In contrast, both ‘ethical’ and ‘allergy’ dimensions were rated as unimportant and ‘convenience’ was rated as neutral, overall.

Table 3.4. Factors influencing the food choices of distance athletes (*median ± interquartile range*) in the adapted questionnaire.

Factor	All (*n* = 19)	Runners (*n* =11)	Cyclists (*n* = 8)
Time	*4.5 ± 2.0*	*4.5 ± 2.0*	*4.8 ± 2.0*
Access*	*5.0 ± 3.0*	*5.0 ± 1.0*	*3.5 ± 3.8*
Convenience	*4.0 ± 2.0*	*4.0 ± 1.0*	*4.0 ± 2.8*
Mood	*5.0 ± 2.0*	*5.0 ± 3.0*	*5.5 ± 1.8*
Sensory appeal	*5.0 ± 2.0*	*5.0 ± 2.0*	*5.0 ± 1.4*
Ethical concern	*2.5 ± 2.0*	*2.0 ± 2.5*	*3.3 ± 2.3*
Allergy	*2.0 ± 3.0*	*2.0 ± 1.0*	*3.0 ± 4.0*
Health**	*5.0 ± 1.0*	*5.0 ± 2.0*	*5.5 ± 1.8*
Physique***	*5.0 ± 1.0*	*5.0 ± 2.0*	*5.5 ± 1.8*
Trust	*5.0 ± 1.5*	*4.5 ± 2.5*	*5.0 ± 1.5*
Somatic	*6.0 ± 1.0*	*5.0 ± 4.0*	*6.0 ± 0.8*
Event	*6.0 ± 2.0*	*6.0 ± 1.0*	*6.0 ± 1.0*
Familiarity	*3.8 ± 4.8*	*5.2 ± 0.0*	*3.5 ± 0.0*

1 = extremely unimportant to 7 = extremely important, with 4 = neutral. Bold factors from the original FCQ (Steptoe, et al, 1995). * Factor includes price items and ** natural content items and ***weight control items from the original FCQ.

The correlations between items outside of their original dimension resulted in eight items being reclassified to ecologically valid dimensions with stronger correlations. As an example, ‘contains natural ingredients’, originally an ‘ethical’ factor correlated more strongly with items within the ‘health’ factor (r_s = 0.45, p = 0.060 increased to 0.60, p = 0.010). Interestingly, ‘contains fibre’ and ‘contains vitamins and minerals’ did not correlate with any items (p >0.05) however, they were rated as important by >50% of participants, which precluded their removal from the ULTRA-FCQ. Instead a new factor ‘nutrients’ was created to differentiate these items. Subsequently, ‘contains protein’ and ‘contains CHO’ both initially considered to be ‘health’ factors were reclassified to this new factor, based on ecological sense. A further 45 items were removed from the ULTRA-FCQ because they were rated as unimportant or neutral (1 - 4) by >50% of participants overall. Consequently, the ULTRA-FCQ consisted of 39 items, covering 11 distinct factors (Figure 3.5).

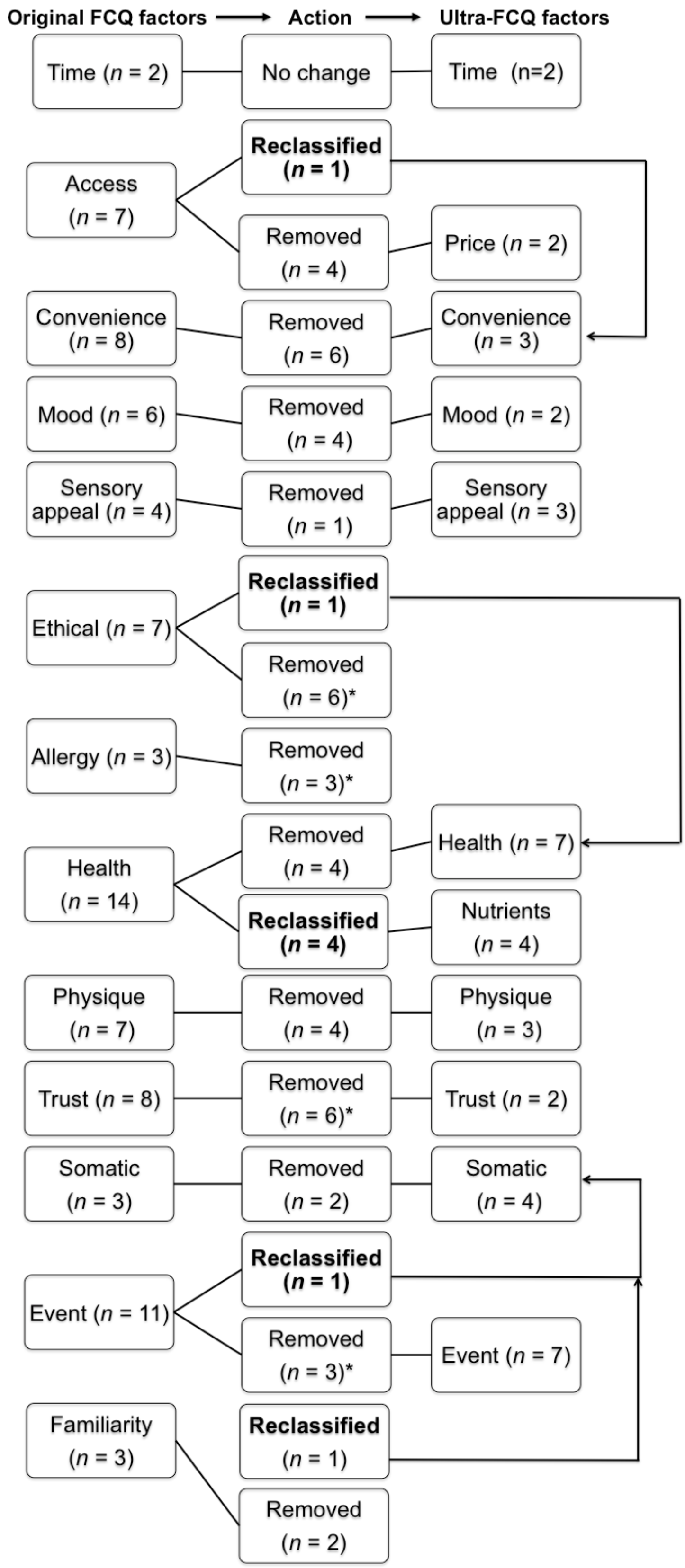


Figure 3.5. Changes to the adapted FCQ, reclassified using exploratory factor analysis and removed if neutral or unimportant to >50% of participants.

The initial completion of the ULTRA-FCQ demonstrated that all 11 dimensions had good internal consistency (Cronbach $\alpha \geq 0.7$), with ‘access’, ‘sensory’, ‘health’ and ‘event’ achieving $\alpha > 0.9$. In terms of the test-retest reliability, the intra-class correlation coefficients (Table 3.5) met the cut off for acceptable retest reliability ($r_s \geq 0.7$) for the majority (n = 8) of factors. Together this data provides evidence of internal consistency reliability for each factor and test-retest reliability for all factors except ‘physique, ‘trust’ and ‘nutrients’.

Table 3.5 Test-retest reliability of the factors included in the ULTRA-FCQ

	Correlation coefficient	Significance (*p*)
Time	0.81	0.001*
Access	0.80	0.001*
Convenience	0.71	0.011*
Mood	0.95	<0.001*
Sensory appeal	0.94	<0.001*
Health	0.90	<0.001*
Physique	0.24	0.309
Trust	0.58	0.036
Somatic	0.88	<0.001*
Event	0.77	0.003*
Nutrients	0.43	0.131

* denotes a statistically significant correlation ($p < 0.05$).

3.8.3 Methods Phase 2: Assessing the Factors Influencing Food Choices of Ultra-Endurance Athletes

3.8.3.1 Participants

One hundred and one ultra-endurance athletes (Table 3.2) who completed the sports nutrition knowledge questionnaire as described in Section 3.3.3.1, also took part in this study.

3.8.3.2 Procedures

After phase 1, a further eight ULTRA-FCQ were added to the questionnaire to gather demographic data, including information about any dietary restrictions or strategies that influenced their food intake. The ultra-endurance athletes completed an electronic version of the questionnaire to rate the importance of the factors that influenced their food choices in preparation for a competitive event between May and November 2014. The questionnaire was conducted through Bristol Online Survey© software (Bristol, England, 2013) and subsequently downloaded and anonymised for analysis purposes. Interested athletes, who did not complete the questionnaire, were sent two reminder emails at 7 and 14 days after initial contact to encourage participation in this element of the study.

3.8.3.3 Data analysis

The same approach adopted in Phase 1 was used to assess the normality of the data in the completed ULTRA-FCQ. The frequency distribution of important, neutral and unimportant ratings was computed for each item in the questionnaire to identify the items of greatest importance.

3.8.4 Results Phase 2: The Factors Influencing Food Choices of Ultra-Endurance Athletes

The majority of athletes were male, runners, who competed in ultra-endurance races within the UK (Table 3.2). Approximately two thirds of athletes were experienced ultra-endurance athletes who had completed >3 ultra-endurance competitions, with more than a quarter completing ≥10 events. In addition, almost 40% of athletes regularly trained for >10 hrs per week. Across this population, dietary restriction and manipulation was common, particularly in the period immediately before and during an ultra-endurance competition (Table 3.6). Notably, only 38.2% of the population studied followed a high CHO diet in preparation for competition.

Table 3.6 Habitual and competition dietary restrictions and manipulation

Dietary restriction or manipulation	Frequency (%)
Habitual diet	
None	74.5
Allergy	13.7
Vegetarian or vegan	10.8
Preparation for competition	
None	38.2
High CHO	38.2
High fat	19.6
Other*	3.9
During competition	
None	16.7
Anti-doping	12.7
Self sufficient	13.7
Minimum nutrition	11.8
Combination of approaches	45.1

*Paleo diet

The rating scores met the criteria for normality (Curran, West and Finch, 1996) with skewness and kurtosis values ranging between 0.301 to 1.743 – and 1.023 to 4.591, respectively. The average rating (mean ± standard deviation) for each factor ranged from 4.4 ± 1.6 to 6.1 ± 0.9 (Table 3.7), with the highest ratings indicating that ‘somatic’ and ‘event’ factors were regard as most important to ultra-endurance athletes overall. Sub-factor analysis identified that ‘does not cause discomfort (gastrointestinal)’ and ‘provides me with energy’ were items considered as extremely important by the majority (>50%) of these athletes (Table 3.8). Furthermore, when important and extremely important ratings were combined the item ‘nutritious’ was also considered to be highly influential to ultra-endurance athletes’ food choices. In contrast ‘easy to prepare’ (50.5%) ‘takes no time to prepare’ (44.5%) ‘quick to cook’ (38.6%) and ‘not expensive’ (38.6%), were the items most commonly ranked as unimportant.

Table 3.7. Factors influencing food choices of ultra-endurance athletes in relation to ultra-endurance competition (Mean ± SD).

Factor	All (n = 101)	Individual items rated as important (≥ 6)	
Time	4.4 ± 1.6		
Access	4.8 ± 1.5		
Convenience	4.6 ± 1.6		
Feelings	5.2 ± 1.3		
Sensory	5.6 ± 1.1		
Health	5.5 ± 1.3	Keeps me healthy	6.0 ± 1.0
		Are nutritious	6.3 ± 0.7
Nutrients*	5.3 ± 1.2		
Physique	5.3 ± 1.3		
Trust	5.3 ± 1.2		
Somatic	6.1 ± 0.9	Are easy to digest before	6.2 ±0.8
		Does not cause discomfort (gastrointestinal)	6.6 ± 0.6
		Does not compromise ability to train or compete	6.3 ± 0.8
Event	6.1 ± 0.9	Give me energy	6.5 ± 0.6
		Helps me cope with high training and comp demands	6.1 ± 0.9
		Can be carried easily	6.3 ± 0.8
		Can be consumed easily	6.2 ± 0.8

* New factor, ethical and allergy factors removed from adapted FCQ, 1 = extremely unimportant to 7 = extremely important, with 4 = neutral.

Table 3.8. Factors rated as extremely important or important for the majority (>50%) of ultra-endurance athletes.

Rating of factors	Athletes (%)
Extremely important	
Do not cause discomfort (gastrointestinal)	62.4
Provide me with energy	52.5
Important	
Tastes good	52.5
Are good quality products	51.5
Combined extremely important and important	
Provide me with energy	96.1
Do not cause discomfort (gastrointestinal)	94.1
Are nutritious	91.1
Easy to consume during training/comp	88.1
Easy to digest before training/comp	86.1
Do not compromise ability to train and/or compete	84.2
Can be carried easy during training/comp	83.2
Help me cope with high training and/or competition demands	80.4
Keep me healthy	78.3
Tastes good	76.5

3.9 Discussion

Understanding the factors that influence the food choices of ultra-endurance athletes could provide vital insight into the barriers affecting adequate nutritional intake for training and competition. Despite this, there appears to be little understanding of the multidimensional nature of food choices within athletic populations (Birkenhead, and Slater, 2015), not least in ultra-endurance groups (Turner-McGrievy, et al, 2016). In athletic populations, the training period has been shown to be a strong influence on their food choices (Smart and Bisogni, 2001), therefore it was deemed that existing tools, which assess the factors that contribute to food choices of general populations, lacked specificity for our intended population. As such, a stepwise approach was employed to enhance the suitability of an existing validated FCQ (Phase 1) for use with a variety of ultra-endurance athletes. In phase 1, evidence was provided for the internal consistency reliability of the ULTRA-FCQ and for the majority of the factors in the questionnaire, acceptable test-retest reliability. Together this indicates that practitioners and researchers could use this tool to assess the level of importance of individual items to their food choices for training and competition.

Completion of the ULTRA-FCQ (Phase 2) revealed that the factors rated as most important to the food choices of ultra-endurance athletes were comparable to those in Phase 1 (somatic and event). Individual items rated as important by the majority of ultra-endurance athletes (>90%) were 'provides me with energy', 'does not cause discomfort (gastrointestinal)' and 'are nutritious'. The provision of 'energy' as a strong driving factor for food selection was unsurprising, as the demands of training and competition can be in excess of three times basal metabolic rate (Hill and Davies, 2001). Current recommendations for optimum performance during prolonged activities focus on CHO intake pre and during competition to maximise muscle glycogen and provide exogenous CHO energy respectively (Burke et al., 2011), however, this is often insufficient to meet the daily energy demands of such prolonged events (Armstrong, 2012 and study 1, chapter 3). Recently there has been new interest in the potential role of short-term HFLC diets for enhancing endogenous fat oxidation, thereby increasing fuel availability

(Burke, 2015). The higher energy density of high fat foods also provides a greater opportunity to meet the athletes daily energy needs.

As hypothesised, the avoidance of GIS achieved the highest importance rating, likely due to the prevalence of gastrointestinal symptoms in triathletes (93%) and in runners (96%) competing in ultra-endurance events (Jeukendrup et al., 1999; Stuempfle & Hoffman, 2015). Furthermore, these symptoms have had a detrimental impact on performance (Stuempfle & Hoffman, 2015). Despite this, Jeukendrup, (2017) has suggested that with familiarisation to CHO intake during training, symptoms of gastrointestinal distress can be moderated. Recent studies have shown promise in this area, with reduced GIS after just two weeks of repetitive CHO intake during training (Costa, et al., 2017; Miall et al., 2017). Although, it should be noted that these studies have been conducted with distance runners in controlled laboratory conditions lasting 2-3 hours, which is considerably shorter than the minimum threshold for ultra-endurance activities.

It is generally accepted that a 'nutritious' diet, rich in vitamins and minerals is essential to the habitual diet of athletes training for ultra-endurance activities (Williamson, 2016). Therefore, with specific nutrients cited as integral to health and optimal metabolic function of the athlete, it is not surprising that >90% of athletes stressed that being 'nutritious' was also important to their food choices. The importance rating for this item (6.4 ± 0.7) was comparable to 'provides me with energy' and 'does not cause discomfort' (6.5 ± 0.6, and 6.6 ± 0.6 respectively), suggesting that they were likely to have a similar level of influence on food choices. Nevertheless, it is possible that these items present as competing influences as nutritious diets; rich in fruit, vegetables, pulses and wholegrain CHOs, which are high in fibre can compromise energy intake and gut comfort (Thomas et al., 2016). As such, these potentially competing influences could partially explain the considerable energy deficits observed during competition (Armstrong, 2012).

Other factors regarded as important by >75% of athletes were ‘tastes good’, ‘are good quality products’ and ‘keep me healthy’, which together may pose a further challenge for ultra-endurance athletes. While sport nutrition products marketed for consumption during competition are good sources of low fibre CHOs, they are often nutrient poor and may have a negative effect on dental health (Bryant, et al, 2011). Furthermore, they are primarily sweet in flavour, and may result in taste fatigue, which may be linked to inadequate nutritional intake in ultra-endurance athletes (Paulin, Roberts, Roberts, & Davis, 2015). Therefore, products that provide variety in taste and texture, and a good source of nutrition without compromising health are likely to be particularly useful in supporting athletes to better meet their nutritional requirements for competition.

Although this study presents a unique insight into the importance placed on factors that influence the food choices during ultra-endurance training and competition, there are some limitations that need to be considered. Firstly, despite acceptable test-retest reliability for the majority of the ULTRA-FCQ the trust, physique and nutrients factors did not meet the minimum threshold set (0.7) by Mitchell and Jolley, (2001). Nonetheless, it is commonly reported that the factors that influence food choices are complex and dynamic, changing to suit the situation or in response to significant events (Furst et al., 1996; Long et al., 2011; Sobal & Bisogni, 2009). Therefore, one could speculate that the dynamic lifestyle of the recreational athlete, such as prolonged training and competing, along with work and family commitments could have affected the stability of motives in relation to food choices between time points, even in such a short period (2-3 weeks).

In addition, a change in the training or competition environment between questionnaires could have influenced the importance of some items. Some events require athletes to be self-sufficient (32.3% of the current population were self-sufficient, with or without minimum nutrition), while others supply adequate nutrition at checkpoints, which may at times mediate the importance of the item ‘Can be carried easy during training/comp’ item. As such, it could be deemed that the retest-reliability is likely to be less important to the design of this questionnaire. Instead, factors that influence food choice during ultra-endurance training and competition should be considered as time and situation specific. Secondly, the ultra-endurance participants who completed the ULTRA-FCQ were predominately male runners, therefore it is unclear if the same observations would be made with females or in other disciplines.

Future studies should seek to recruit a large sample of ultra-endurance athletes with equal distribution of ultra-endurance sporting disciplines. This would facilitate sub-groups analysis to determine if there are any substantial differences in the factors that influence food choices. Finally, the ULTRA-FCQ provides a snapshot of the factors that influence the food choices of ultra-endurance athletes for specific training and competition periods, rather than an understanding of the dynamic processes involved in food choice (Sobal et al, 2009) for this population. Nonetheless, the ULTRA-FCQ may be seen as efficient tool that could supplement knowledge of the demands of the sport to enable professionals working with this population group to devise a nutrition plan that is both effective and acceptable to individual athletes.

3.10 Conclusion

The most prominent factors to influence the food choices of ultra-endurance athletes during training and competition were the avoidance of GIS, the demand for energy and the desire for nutritious foods. All three factors were rated as important by the majority of participants and may present as conflicting motives that contribute to the suboptimal nutritional intake that is commonly reported in this athletic group. To enhance the nutritional intake and fuel availability for ultra-endurance competition, intervention studies need to introduce strategies that address the main factors that influence their intake (Study 3, Chapter 4). Priority should be placed on strategies to improve GI tolerance to CHO during exercise and those capable of increasing the rate of endogenous fat oxidation. The latter is especially important when glycogen stores are likely to be compromised and it is anticipated that CHO consumption will be below the recommended rates for ultra-endurance activities. Furthermore, future studies may benefit from exploring how ultra-endurance athletes negotiate the potentially competing factors that influence their food choices for competition (Study 4, Chapter 5). This would provide a pivotal opportunity to gain a greater understanding of the challenges they face in meeting the considerable fuel demands of their sport.

Chapter 4: Efficacy of a Multicomponent Strategy to Improve Ultra-Endurance Performance, Gastrointestinal Symptoms and Nutritional Intake

4.1 Study 3: Efficacy of a Multicomponent Strategy to Improve Ultra-endurance Performance, Gastrointestinal Symptoms and Nutritional Intake

4.2 Introduction

The suboptimal nutritional intake typically reported by ultra-endurance athletes, both during and in preparation for training and competition (Section 2.4 and Chapter 3, study 1) are likely due to a range of competing motives. While the majority (96.1%) of ultra-endurance athletes who took part in Study 2 (Chapter 3, Table 3.8) indicated that their food choices for competition were motivated by the need to meet the energy demands of the race, this is likely moderated by the drive to avoid GIS and preferences for nutritious foods (Section 3.9). Interestingly, commercially available sports products that are promoted to athletes for the supposed optimal CHO ratio (2:1 glucose fructose) and osmolality, are not only nutrient poor, but result in taste fatigue due to the overly sweet flavour (McCubin, cox & Board, 2016). As such, ultra-endurance athletes often favour real foods, selecting a combination of sweet and savoury items that likely diverge from current nutritional recommendations (Section 2.3.2.2).

Given the potential mechanisms underlying the development of GIS (outlined in section 2.5.3.1), ultra-endurance running is likely to cause symptoms that impair performance. Furthermore, GIS may be exacerbated by inappropriate nutritional intake, particularly fluid and nutrient strategies that results in excessive dehydration and delayed GE. In contrast, recent studies suggest that familiarising runners to recommended rates of CHO during training (90 g in the first hour of training) could reduce the incidence of GIS (Costa, et al., 2017; & Miall, et al., 2017), however the transferability of these findings to ultra-endurance distance events is unknown. In addition, the logistical challenges of carrying recommended volumes of fluid and CHO may negate any beneficial effect of reduced GIS on performance. Given the challenges in meeting the energy and fuel demands of ultra-endurance events, a single component nutrition strategy that focuses solely on GT is unlikely to optimise performance. Instead, interventions should combine strategies proposed to optimise endogenous and exogenous fuel availability.

Carbohydrate is regarded as superior to fat for performance during endurance activities (Thomas, Erdman, & Burke, 2016), however glycogen storage capacity and low tolerance to CHO intake during competition can restrict fuel availability. Acute fuelling strategies are capable of inducing muscle glycogen supercompensation (Burke, et al., 2011) and increasing exogenous CHO oxidation (Cox Snow & Burke, 2010), translating into increased CHO availability. However, when exogenous CHO availability is limited by the logistics of competition, strategies to enhance fat oxidation may be superior for ultra-endurance performance. Increased fat oxidation has been observed after both short and long-term HFLC diets (Section 2.3.1.3), however to date it is unclear whether this has a beneficial effect on performance. Therefore, the primary aim of this study was to assess whether a multicomponent nutrition strategy designed to enhance CHO intake and fat availability (GT + HFLC diet) was superior to a multicomponent strategy designed to increase CHO intake and CHO availability (GT + LFHC diet) for ultra-endurance performance. The secondary aims were (i) to assess whether GT was capable of reducing the incidence and severity of GIS and (ii) to determine whether GT would enable ultra-runners to match their ad-libitum CHO intake with the current CHO recommendations. Based on existing literature (Costa, et al., 2017; Miall, et al., 2017), it was hypothesised that GT would reduce ultra-runners' GIS and enable them to meet the recommended rate of CHO intake. In the event that this hypothesis was accepted, it was hypothesised that runners allocated to the GT + LFHC diet would outperform their matched equivalents, following the GT + HFLC diet.

4.3 Methods

This study employed a two-phased dietary intervention to address the main barriers to optimal nutritional intake and performance (Chapter 3). In phase 1, a GT diet was designed to improve GI tolerance to food and fluids during training and competition, in an effort to support ultra-runners to match the CHO recommendations for prolonged exercise. While phase 2, combined two nutritional strategies in an attempt to optimise fuel availability during competition and subsequently enhance performance.

4.3.1 Participants

The Institutional Research Ethics Committee approved this study prior to recruitment. Seventeen experienced distance runners (males, *n* = 16, females, *n* = 1) who had completed at least one ultra-endurance race in the past 3 years (or >2 marathon distance races) took part in all elements of this two-phased nutrition intervention study (Table 4.1). These experienced distance runners aged 41.9 ± 4.8 years, VO_{2peak} 52.7 ± 7.9 ml.kg-1.min^{-1}, provided written informed consent after being informed of the potential risks associated with the overall study protocol and individual procedures (Figure 4.1).

Table 4.1. Comparison of baseline characteristics for participant between diet intervention groups.

Baseline	GT + HFLC (n = 8)*	GT + LFHC (n = 9)	Significance, effect size**
Ultra-runner characteristics			
Age (years)	41.3 ± 4.1	42.6 ± 5.6	p = 0.595, r = 0.14
Weight (kg)	77.6 ± 11.9	76.5 ± 10.6	p = 0.904, r = 0.11
Height (cm)	178 ± 5.2	176 ± 7.8	p = 0.429, r = 0.22
Body fat (%)	17.2 ± 6.8	19.2 ± 7.2	p = 0.567, r = 0.14
Fitness and experience			
Velocity at 4 mmol.l (km.hr^{-1})	12.9 ± 1.4	12.6 ± 1.7	p = 0.703, r = 0.06
VO_2max (ml.kg^{-1}.min^{-1})	52.9 ± 2.3	52.5 ± 8.1	p = 0.918, r = 0.06
Peak velocity (km.hr^{-1})	16.5 ± 1.8	16.5 ± 2.3	p = 0.1.00, r = 0.04
Best marathon time (min)	227.5 ± 41.7	236.1 ± 54.2	p = 0.721, r = 0.08
Completed events (n)	4.0 ± 2.6	5.1 ± 2.7	p = 0.405, r = 0.25
Gut symptoms during a training run >3 hr			
Number of symptoms (n)	*3.5 ± 2.0*	*5.0 ± 2.5*	*p = 0.171 r = 0.39*
Severity of symptoms (1 - 9)	*3.0 ± 3.0*	*5.0 ± 3.0*	*p = 0.083, r = 0.49*

mean ± standard deviation, *median ± interquartile range,* *one participant excluded as performance time was 2 standard deviations below the average, **comparison of participant characteristics at baseline between GT + HFLC and GT + LFHC groups.

4.3.2 Procedures

4.3.2.1 Recruitment and Eligibility

As part of this study, all participants were required to take part in a 56 km ultra-endurance race. To identify appropriately trained endurance runners for the race, who were available to complete the study requirements, the research project was promoted via a UK research website, which was advertised on social media. Sixty-five interested distance runners completed an online screening tool to check their eligibility against the study inclusion criteria:

- Healthy, experienced endurance runners
- Aged 18-60 years
- Completed at least 1 ultra-endurance race in the last 2 years
- Free from allergy and existing GI disease
- Available to complete all elements of the research protocol (Figure 4.1).

4.3.2.2 Preparations and Baseline Assessment

Self-reported eligible and available runners (*n* = 23) subsequently attended the laboratory for screening and fitness assessment tests (Visit 1, Figure 4.1). All participants arrived in a fasted state between 8 and 10 am and completed a health screening form and a physical activity readiness questionnaire, prior to any physical tests. This was followed by measurement of resting HR and blood pressure, along with capillary blood samples for total cholesterol (Accutrend® Plus System, Roche Diagnostics, USA), blood glucose (HemoCue Glucose 201+, Angelholm, Sweden) and haemoglobin (HemoCue Hb 201+, Angelholm, Sweden), to ensure that participants were safe for maximal testing and the demands of the 56 km race. Anthropometric measurements were completed while wearing minimal clothing and after voiding their bladder. Height and weight were measured immediately before estimating fat and fat free mass via air displacement pleythysmography, using a BOD POD® system. This method of estimating fat mass has demonstrated high correlation with the reference technique, dual energy x-ray absorptiometry (*r* = 0.94) resulting in a MD of 2.2% among men aged 32 ± 11 years (Stephen & Thomas, 2004).

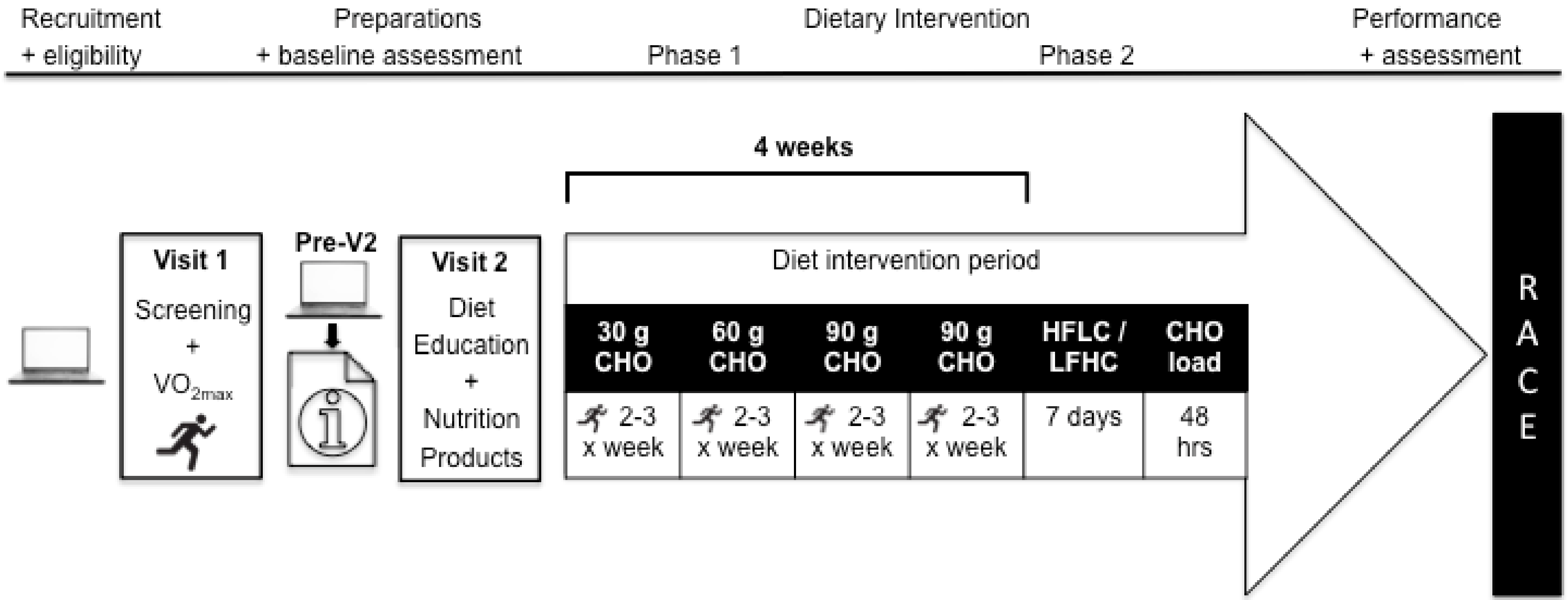


Figure 4.1. Schematic representation of the overall study protocol, which was completed by participant. VO_{2max} = maximal oxygen uptake during an incremental treadmill test, CHO = carbohydrate intake. HFLC = high fat, low CHO diet, LFHC = low fat, high CHO diet.

One runner presented with elevated blood pressure and was excluded from taking part. The remaining 22 participants completed the final element of fitness assessment, which was an incremental treadmill test to exhaustion. This consisted of a 5-minute warm-up at the participant's individual warm-up pace, followed by 4-minute intervals at increasing velocity (1 km per interval). Blood lactate was measured from a blood sample taken from the index finger (Lactate Pro 2 Analyser, Kodak Ektachem, Analox and Accusport) immediately before, after each increment (until blood lactate exceeded 7 $mmol.l^{-1}$) and after participants voluntarily terminated the test. The Lactate Pro 2 was chosen for its speed of analysis and its reasonable reliability compared to a criterion blood analyser (Model ABL90, Radiometer, Copenhagen, Denmark), indicated by a coefficient of variation <5% at concentrations ranging from 2 to 15+ $mmol.l^{-1}$ (Bonaventura, Sharpe, Knight, Fuller, Tanner & Gore, 2015).

Once blood lactate increased beyond 7 $mmol.l^{-1}$, the treadmill velocity was increased every minute until volitional exhaustion. Throughout the test, breath-by-breath respiratory gases were analysed (every 10 seconds) using Metamax 3B (Cortex Biophysik GmbH, Leipzig, Germany) to estimate maximal oxygen uptake (VO_{2max}). This device has been reported to have acceptable reliability when compared to criterion measurements (custom-built indirect calorimetry system with an automated Doughlas bag), with the reliability error for VO_2 ranging between -4.1 to 2.8% across 5 steady state settings (Vogler, Rice & Gore., 2010). Failure to achieve criteria for VO_{2max}, determined using British Association of Sport and Exercise Science guidance in the minority of participant resulted in the maximal oxygen uptake data being reported as

VO_{2peak} (Jones, Winter, Davidson, Bromley and Mercer, 2016). Results from the completed assessments allowed participants to be matched on these characteristics into one of two dietary intervention groups for phase 2 of the intervention.

Approximately 3 weeks prior to attending the laboratory for the second time (Pre-V2, Figure 4.1) all participants completed a series of online questionnaires to capture their usual nutritional practices and baseline characteristics. Firstly, the sports nutrition knowledge questionnaire (ULTRA-Q) and the food choice questionnaire (ULTRA-FCQ), which were both designed for ultra-endurance athletes (Chapter 3, study 1 and study 2, respectively) were completed to establish baseline knowledge and the factors that influence their food choices. Participants subsequently reported their typical nutritional intake for ultra-endurance training and competition, their food and fluid dislikes along with their typical training routine in the lead up to an ultra-endurance race. Finally, participants documented the prevalence and severity of 16 GIS on a 10-point likert type scale (Pfeiffer et al., 2012) during a prolonged training run (>3 hr) to establish their 'normal' GIS prior to the dietary intervention (Table 4.1). The scale ranged from 0 – 9, with 0 indicating 'no symptoms' and 9 representing symptoms that were as 'worse as they could be' and a score >4 was considered to represent severe symptoms (Pfeiffer, et al., 2012). While the validity and reliability of this tool has not been evaluated, it was favored over the GIS rating scale (Section 2.5.3.2), due to the comprehensiveness of the items included in the instrument. Together this information was used to tailor both phases of the dietary intervention to each participant's individual requirements and taste preferences, while considering the factors that influenced their food choices.

In addition, results from the ULTRA-Q, ULTRA-FCQ and GIS questionnaires were used to develop educational resources to support compliance with the dietary intervention. Overall sports nutrition knowledge for the participants was 63.2 ± 10.9%, with the lowest knowledge score for the fluid questions (50.0 ± 14.7%). This was reflected in the education session with appropriate attention paid to the fluid section and individual questions that may have influenced their understanding of the dietary intervention. The factors rated as important or extremely important to the food choices of the majority (>80%) of participants (Table 4.2) included the avoidance of GIS. Providing a clear rationale for the first phase of the dietary intervention.

Table 4.2 Factors rated as extremely important to the food choices of ultra-endurance runners during periods of high volume training, in preparation for competition

Factor	Frequency (%)
Quality of the food	100
Easy to consume during exercise	94.1
Easy to carry during exercise	88.2
Easy to digest before exercise	88.2
Gives me energy	88.2
Does not cause discomfort (gastrointestinal)	87.6
Nutritious	82.3
Does not compromise ability to compete	82.3

Approximately 7 weeks before the race, participants attended the laboratory a second time for group based dietary education in preparation for both phases of the intervention. One participant was unable to attend the dietary education session due to family commitments, but wished to remain in the study. As such, verbal instructions for both phases of the dietary intervention were provided by telephone and supporting resources were sent via post. The group education session delivered by a Registered Dietitian (principle investigator), lasted 45 minutes and covered the following topics (i) purpose of the dietary intervention, (ii) nutritional content of the dietary intervention (iii) instructions on how to follow the individual diet plan and (iv) research requirements during the dietary intervention.

Subsequently, participants had the opportunity to ask questions before becoming familiarised with their individual diet plans and their supporting resources. This included research logs to record their dietary compliance (phase 1 and 2) and to monitor any changes to their GIS (phase 1 only). In addition, they were provided with a variety of sports nutrition products for ingestion during the GT period (phase 1) and for CHO-loading, two days prior to the race (phase 2). A combination of 8.8% CHO drinks (high five energy source 2:1 glucose, fructose), energy gels, isogels, sports sweets (shotbloks) electrolyte tablets, and high 5 energy bars were provided for the GT period. In addition, participants were given between six and 10 energy drinks (Science in Sports, 50 g CHO each) to supplement their CHO intake during the CHO-loading period. All participants were encouraged to record any deviations from their diet plans to obtain a true reflection of their dietary compliance. In addition, they were invited to contact the principle investigator during the intervention period if they had any questions regarding the diet plan.

4.3.2.3 Dietary Intervention

The GT element of the intervention (phase 1) required all participants to gradually increase the volume of CHO consumed in the first hour of training sessions, over a four-week period as illustrated in Figure 4.1. This was in an attempt to improve the participant's GI tolerance to CHO and improve CHO availability during the race (Costa, et al., 2017), with a view to achieving the recommended CHO intake (Burke et al., 2011). To meet these targets and to facilitate adaptations specific to the types of CHOs ingested (Costa, et al., 2017) participants were instructed to consume CHO rich products that aligned with their preferences, from a list of items that were available during the race. This included the sports products provided during visit 2 and a range of foods from their normal training and competition nutrition (i.e. fruit, malt loaf and sweets).

As the majority of participants reported avoiding fluids during training sessions lasting <2 hr, they were instructed to gradually increase the volume of fluid consumed during the 60 minute GT sessions. Participants started in week one with what was comfortable for them and aimed to increases this over the four-week period to minimise the level of dehydration during the race, i.e. <2% body mass loss (Sawka et al., 2007). Participants determined their maximum fluid target at home, estimating their individual sweat rate from their change in body mass during a 1 hour run at their self-selected running pace for the race (Sawka et al., 2007). Although when sweat rates were high and deemed excessive, a maximum fluid target of 800 ml (Noakes, 2003) for the GT session was agreed with the researcher. Dietary compliance was monitored for all GT sessions and GIS were recorded for the participant's longest training run each week.

Immediately after the GT period, participants were matched to one of two groups for phase two of the dietary intervention (Figure 4.1). This was based on the treadmill test results and the anthropometric measurements obtained during the first laboratory visit (Figure 4.1). Participants in these groups were allocated to either a HFLC or LFHC diet, which they followed for 7 days. The HFLC diet was prescribed to stimulate fat adaptation (Burke, et al., 2000) and it consisted of a fat target equivalent to 60% of estimated energy requirements and a CHO target of approximately 25% of the individual participant's energy needs (Burke, 2015). The proportion of fat and CHO was reversed for the LFHC diet, however, the percentage of energy from protein and energy balance was consistent in both groups. All participants commenced their respective diet 9 days before the race. Subsequently, both diet groups were instructed to consume a high CHO diet for 48 hr (CHO-loading) to promote maximum glycogen storage, with a target of 10 $g.kg^{-1}$ per 24 hr (Burke et al., 2011).

To support dietary compliance, each participant was given a personalised diet plan that included specific targets for each of the five basic food groups. This was supported with an example of how to meet their targets for a typical training day, rest day and CHO-loading day. The latter example incorporated the energy drinks provided during visit 2. Compliance with the preparation diet was monitored over 3 days comprising two days HFLC or LFHC and one day CHO-loading, to minimise participant burden. The principle investigator reviewed the GT logs and the preparation diet logs for completeness prior to nutritional analysis. Subsequently, the dietary intake was compared to the nutritional targets for their allocated diet.

4.3.2.4 Race Day

Three participants dropped out of the study prior to race day due to muscular skeletal injury. The remaining participants reported to the race headquarters located next to the laboratory in a fasted state between 6 and 7am on the morning of the race. On arrival all 18 participants completed a series of laboratory tests that were repeated immediately post-race to provide an indication of the overall changes to hydration status, GIS and key blood markers. Firstly, urine osmolality obtained from a mid-flow urine sample and analysed using a portable urine analysis unit (Osmocheck, Vitech Scientific Ltd, West Sussex, UK) was combined with pre and post-race body mass (measured using the protocol in 4.2.2) as an index of hydration status (Sawka et al., 2007). Post-race body mass was adjusted for fluid ingested between measurements, to provide a crude estimation of the change in hydration status. Secondly, participants self-reported the prevalence and severity of GIS experienced before and during the race. Finally, fingertip capillary blood samples were analysed using a criterion blood gas analyser (Model ABL90 FLEX, Radiometer, Copenhagen, Denmark) in order to measure electrolytes and metabolites (glucose and lactate). A third capillary blood sample was obtained on completion of lap 5 to provide interim data. After the pre-race measurements participants were provided with a standardised pre-race breakfast that was low in fibre, fat and protein and provided 1.2 ± 0.22 $g.kg^{-1}$ of CHO (Burke et al., 2011).

The race took place in mid-September on a dry sunny day, (mid-race conditions were; temperature 20 ^{o}C; humidity 53%; and barometric pressure 999.7 mmHg) on the University campus. The route consisted of 10 laps of a model5.6 km course and included a range of running surfaces with a total of 225 m accent over the 56 km (Figure 4.2). The race was open to research participants only, however, care was taken to simulate race conditions as closely as possible, by providing a prize for the winner along with medals and event t-shirts for all race finishers. In addition, all participants wore a race number throughout the event, to facilitate the recording of performance times. All participants wore a wristwatch with Global Positioning System (GPS) technology (model Garmin Forerunner 15) to record their running pace over the 10-laps. Each wristwatch was paired with a chest belt that concurrently recorded heart rate and provided an estimate of energy expenditure. Participants activated their individual GPS devices prior to the start of the race, but recording of heart rate and pace only commenced once the race started.

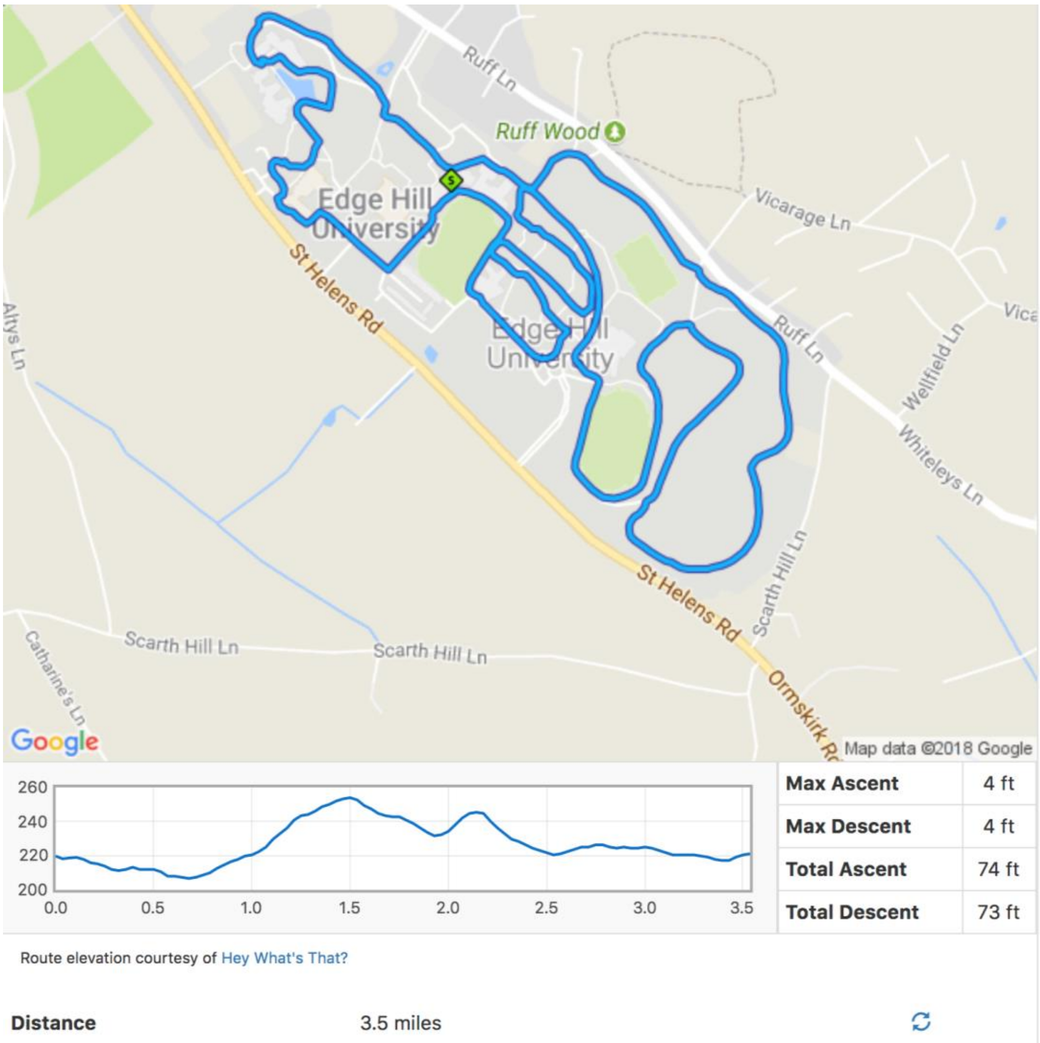


Figure 4.2. Characteristics of the 5.6 km (3.5 mile) race lap

Four researchers were responsible for the accurate recording of the performance times and Borg rating of perceived exertion (RPE) of all participants (Borg, 1998). Each lap time was recorded manually using a timing app (Webscorer Pro, Webscorer Inc, Woodinville, Washington, USA) and confirmed by a second researcher who was equipped with a stopwatch and record chart. The third researcher recorded RPE as each lap was completed. To facilitate this a flipchart displaying the RPE scale was displayed 10 m before the lap/finish line to prompt the athletes. The researchers rotated their roles to avoid fatigue and were supported by a fourth researcher to allow food, fluid and comfort breaks due to the prolonged nature of the race. The GPS data was used to confirm the timing app and stopwatch records to ensure accurate recording of the performance data.

Nutrition was provided at two aid stations across the 5.6 km course, roughly at 2.8 km and 20 m before the end of the loop. A variety of sports products (as described in section 4.3.3) and ‘real foods’ (i.e. cakes, flapjacks, fruit and pretzels) were available at each aid station, along with plain water. Nutritional intake during the race was ad-libitum, however, participants were instructed to aim for 90 $g.hr^{-1}$ of CHO and to consume fluid at a rate that was reflective of their individual sweat rates. They were not permitted to consume any foods or drinks that were not provided at the aid stations.

A team of nutrition students, who were trained to keep accurate dietary records, recorded the nutritional intake of each participant at both aid stations for the duration of the race. They recorded the food type, amount and waste against the participant’s race number. To facilitate this, all food and drinks were presented at the aid stations in standardised portions that were weighed out using a set of digital scales. Participants were instructed to return any items that they did not consume during the lap to the next available aid station. The nutrition students estimated the weight of all returned items on the same dietary record. Post-race these records were reviewed for completeness and legibility by the principle investigator. Subsequently, the nutritional intake of all participants during the race (and during the diet intervention period) was analysed using professional analysis software (Nutritics version 3.7 Professional). The same Registered Dietitian completed the nutritional analysis on two separate occasions to ensure accurate representation of the athlete's nutritional intake. Any inconsistencies in the nutritional analysis between the two time periods were investigated by comparing the participant's diet logs to the food log input into Nutritics. Adjustments to the food logs were made to rectify any inaccurate records.

4.3.3 Data analysis

Prior to the main statistical analysis, the data was screened for normality. Skewness and kurtosis values of <2.0 and <7.0 respectively were considered to indicate reasonable normality (Curran, West and Finch, 1996). Subsequently, a comparison of the baseline characteristics between participants assigned to the HFLC and LFHC diets was completed using a series of Mann Whitney U tests. Subsequently, dietary compliance for both phases of the intervention was assessed using a combination of paired samples t-tests (all participants) and multivariate analysis of variances (MANOVA), the latter for sub-group analysis. Pillai's Trace statistics were the MANOVA statistics of choice due to the relatively small sample size and uneven participant numbers (Tabachnick and Fidell, 2007). Subsequently, the post-hoc tests of between-subject effects with adjusted *p*-values were reviewed to locate the sources and direction of any significant differences. In response to the screening for normality, Wilcoxon signed rank tests were used to assess for changes in incidence and severity of GIS after GT. The relationship between GIS and key variables (i.e. markers of hydration and urine osmolality and nutritional intake) was assessed using Pearson's and

Spearman's correlation coefficient for parametric and non-parametric data, respectively.

Overall performance time for the HFLC and LFHC intervention groups was compared using an independent samples t-test. To assess for group differences in absolute performance (lap velocity, RPE values HR), relative performance (percentage of velocity at VO_{2peak}) and percentage of maximum HR), nutritional intake and key metabolites (glucose and lactate) over time, several MANOVA were computed as described above. One-way repeated measures analysis of variance (ANOVA), with Wilks' Lambda as the statistic of choice (Pallant, 2016) assessed the impact of time on this data for all participants, during the race. Tukey post-hoc pairwise comparisons were reviewed to identify the source of any significant differences. Furthermore, a MANOVA was computed to determine whether there were any statistically significant differences in the dietary intake of ultra-runners assigned to the HFLC and LFHC groups.

To minimise the risk of type 1 error, the *p*-value for these tests was adjusted using a Bonferroni correction for the number of variables. Effect sizes were calculated for all difference tests as follows. In relation to both the MANOVA and ANVOA statistics, partial eta squared (ηp^2) was computed with 0.10, 0.25 and 0.50 signifying small medium and large effect sizes respectively (Cohen, 1965). Cohens d was computed for the t-test statistics, with 0.2, 0.5 and 0.8 regarded as small medium and large effects respectively (Cohen, 1988). Finally, for the Mann Whitney U test and Wilcoxon signed rank test the rank biserial correlation was used to determine the effect size, with values of <0.2

<0.4 <0.6 and < 0.8 representing very weak, weak, moderate and strong effect sizes, respectively (Evans, 1996). All data was analysed using IBM© SPSS© (version 22) with a significance value of p = 0.05 for all tests unless otherwise specified.

4.4 Results

All 18 participants completed the race, however, one female participant was excluded from the data analysis as her performance time (540.0 min) was slower than two standard deviations (491.8 min) from the average time (364.0 min) (Rowlands & Houltham, 2017).

4.4.1 Comparison of Ultra-endurance Performance Between Dietary Intervention Groups

There was no difference in mean performance time for the 56 km race between the GT + HFLC and GT + LFHC diet groups (353.6 ± 42.8 min and 354.1 ± 54.3 min, respectively), t (15) = 0.20, p = 0.984, d = 0.10 (MD 0.49: 95% CI -50.6 to 51.5). Therefore, the performance hypothesis has been rejected. Furthermore, absolute (Figure 4.3a) and relative (percentage of velocity at VO_{2peak}) running velocity was comparable between groups for each lap throughout the race, F (10, 6) = 0.74, p = 0.681, Pillai's Trace = 0.55, η_p^2 = 0.55 and F (10, 4) = 0.77, p = 0.665, Pillai's Trace = 0.67, η_p^2 = 0.67, respectively. When the running velocity for all participants was analysed over the duration of the race, a statistically significant effect of time was revealed, λ = 0.11, F (9, 8) = 7.45, p = 0.005, multivariate η_p^2 = 0.82. Post-hoc analysis indicated that mean running velocity was relatively stable from the start until lap five, when participants stopped briefly for their mid-race capillary blood samples. Subsequently, a significantly slower velocity was evident for the final four laps, p <0.01.

There were no statistically significant differences between GT + HFLC and GT + LFHC groups for either absolute HR (Figure 4.3b), relative HR (%HR_{max}) or RPE (Figure 4.3c) over the 10 laps, F (10, 1) = 0.56, p = 0.788, Pillai's Trace = 0.85, η_p^2 = 0.85, F (10, 1) = 0.96, p = 0.669, Pillai's Trace = 0.91, η_p^2 = 0.91, respectively and F (10, 5) = 0.68, p = 0.717, Pillai's Trace = 0.58, η_p^2 = 0.58, respectively. A significant effect of time was observed for the RPE of all participants, λ = 0.04, F (9, 7) = 19.58, p <0.001, multivariate η_p^2 = 0.95. The post-hoc analysis indicated significantly higher RPE scores for laps five to 10 compared to laps one to four (p <0.05). There were no differences in RPE ratings between Laps one and four, or Laps eight to 10, p >0.05. Furthermore, there was no significant difference in the participants HR over the course of the race, λ = 0.05, F (9, 3) = 6.29, p = 0.079, multivariate η_p^2 = 0.95.

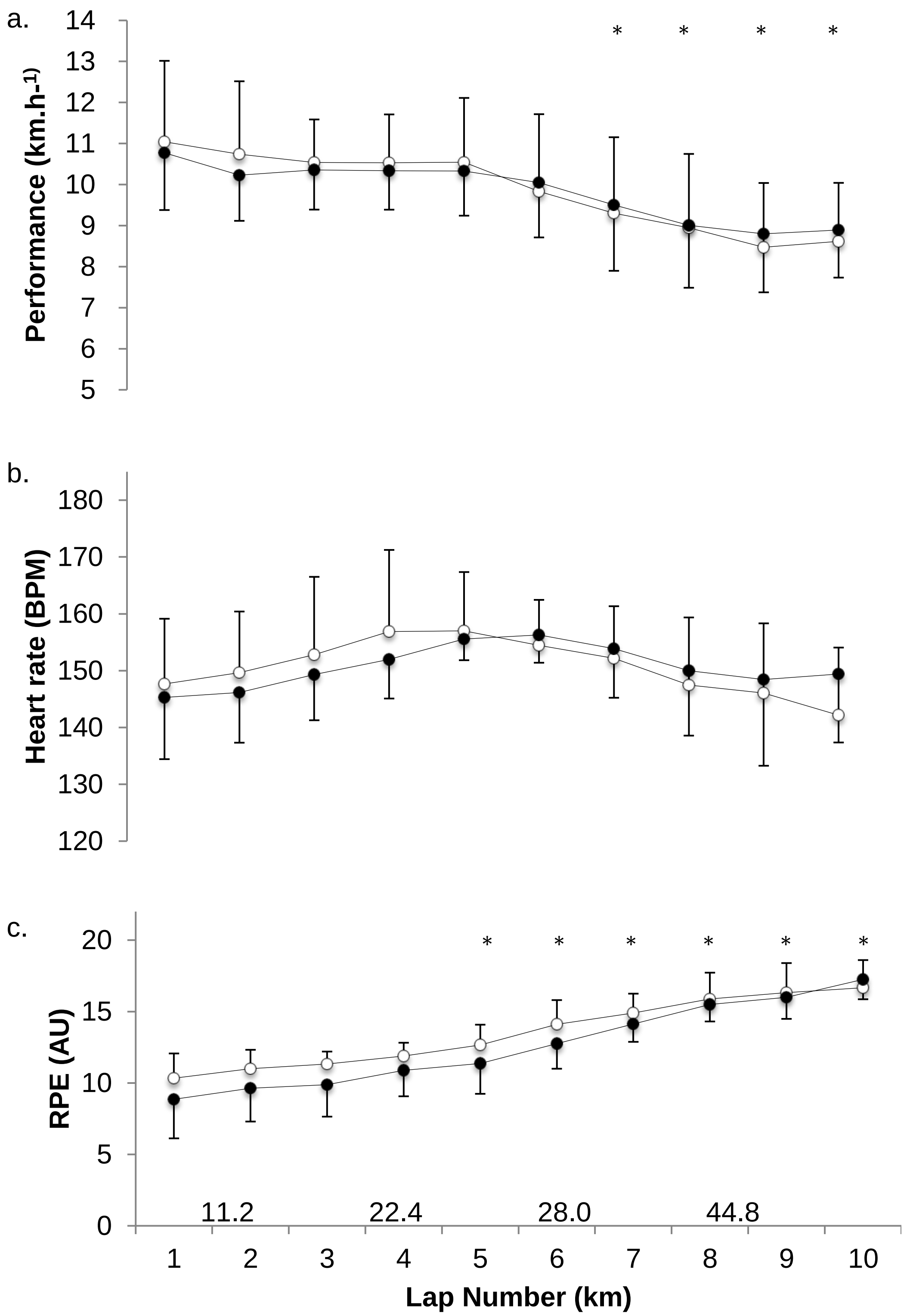


Figure 4.3. Race performance data for HFLC (white) and LFHC (black) intervention groups (means ± standard deviation). BPM = beats per minute, RPE = rating of perceived exertion, *significantly higher RPE and slower velocity for both groups compared to lap 1.

4.4.2 Comparison of Baseline Characteristics and Dietary Compliance

Subgroup analysis indicated that there were no significant differences in baseline characteristics for participants assigned to the GT + HFLC (*n* = 8) and GT + LFHC (*n* = 9) diet groups (Table 4.1). The GT + LFHC group experienced significantly more GIS during running at baseline compared to the GT + HFLC group, *U* = 5.5, *z* -2.96, *p* = 0.003, *r* = 0.85. Dietary compliance for all ultra-runners (*n* = 17) was evidenced during the GT phase (Table 4.3), as there were no significant differences between CHO intake and CHO targets (*p* = 0.350 to 0.842), except in week 1. During this week, ultra-runners consumed significantly more CHO than was required, mean difference (MD) 8.12 g, *t* (15) = 2.79, *p* = 0.036, *d* = 1.44 (95% confidence interval (CI): 1.90 to 14.33). Equally, there was no difference in the proportion of fat consumed compared to the respective fat targets for the GT + HFLC or the GT + LFHC group, MD -0.81%, *t* (15) = -0.97, *p* = 0.350, *d* = 0.50 (95% CI: -2.61 to 0.98).

In contrast, ultra-runners consumed a significantly lower proportion of CHO than was prescribed during both the preparation and the CHO-loading phase of the intervention, MD of -4.74%, *t* (15) = -5.06, *p* < 0.001, *d* = 2.62 (95% CI -6.74 to -2.74) and MD -3.06 g.kg^{-1}, *t* (15) = -8.92, *p* <0.001, *d* = 2.62 (95% CI -3.79 to -2.33), respectively. However, both GT + HFLC and GT + LFHC saw a significant increase in the rate of CHO ingestion from the preparation diet to the CHO-loading diet, MD 4.8 g.kg^{-1}, *t* (7) = 14.0, *p* <0.001 (95% CI: 3.95 to 5.6 g.kg^{-1}) and MD 2.2 g.kg^{-1}, *t* (7) = 6.0, *p* = 0.001 (95% CI: 1.3 to 3.1 g.kg^{-1}), respectively.

Subgroup analysis indicated that there was a statistically significant difference in the nutritional intake between the GT + HFLC and the GT + LFHC group during the intervention period (including the GT diet and the preparation diet i.e. HFLC or LFHC and CHO-loading), F (7, 8) = 87.74, λ= 0.13, p <0.001, ηp^2 = 0.99. As expected, post hoc analysis revealed that the significant difference between the GT + HFLC and GT + LFHC groups was for the 7 day allocated diet (HCLF or LFHC) during phase 2 of the multicomponent intervention only. There were no other differences in CHO intake during the GT diet or CHO-loading periods.

As required, the GT + HFLC group consumed a significantly higher percentage of fat and a significantly lower percentage of CHO (p <0.001) compared to the GT + LFHC group (Table 4.3). Although the CHO intake during the preparation diet was below the group targets, this was marginal (HFLC lower by 6.0% and LFHC lower by 2.7%). Whereas, the rate of CHO consumed by HFLC (6.6 ± 2.1 $g.kg^{-1}$) and LFHC (8.1 ± 2.9 $g.kg^{-1}$) groups represented just 66% and 81% of the CHO-loading targets (10 $g.kg^{-1}$), respectively.

Table 4.3. Comparison of the CHO and fat intake during the diet-monitoring period between the HFLC and the LFHC groups.

	GT diet				Preparation diet		
	Week 1 $g.hr^{-1}$	Week 2 $g.hr^{-1}$	Week 3 $g.hr^{-1}$	Week 4 $g.hr^{-1}$	CHO %	Fat %	CHO-loading $g.kg^{-1}$
Ultra-runners							
All	38.1 ± 11.7	60.6 ± 12.0	91.2 ± 9 g	91.4 ± 28.4	n/a	n/a	6.9 ± 1.3
HFLC							
Intake	32.7 ± 25.4	62.5 ± 8.8	91.1 ± 18.8	90.5 ± 12	19.0 ± 5.0	58.0 ± 4.6	6.6 ± 2.1
Target	30	60	90	90	25	60	10
LFHC							
Intake	39.7 ± 168.9	61.2 ± 23.8	90.1 ± 9.3	91.5 ± 26.8	57.3 ± 7.0	25.0 ± 5.5	8.1 ± 2.9
Target	30	60	90	90	60	25	10
F	0.46	0.28	3.47	2.17	434.29	418.02	1.93
p	0.508	0.604	0.084	0.163	<0.001*	< 0.001*	0.187
η_p^2	0.03	0.02	0.20	0.13	0.97	0.97	0.12

mean ± standard deviation *Significant difference p <0.01 between HFLC and LFHC intervention groups

During the race, the average rate of macronutrient, electrolyte, fibre and fluid intake for the GT + HFLC and GT + LFHC groups during the race (Table 4.4) were not significantly different, F (7, 9) = 0.46, p = 0.841, Pillai's Trace = 0.26, ηp^2 = 0.26. Notably, there was considerable intra-runner and intra-lap variability in the volume of CHO consumed during the race (Figure 4.4), however, statistical analysis indicated that there was no diet, distance interaction, F (5, 11) = 1.64, p = 0.230, Pillai's Trace = 0.43, ηp^2 = 0.43. In both groups, ultra-runners consumed their lowest rate of CHO in lap one (HFLC 13.9 ± 30.2 $g.lap^{-1}$ and LFHC 19.7 ± 15.6 $g.lap^{-1}$). Whereas the highest rates of CHO were seen in laps seven (41.7 ± 13.4 $g.lap^{-1}$) and two (49.8 ± 28.2 $g.lap^{-1}$) for the HFLC and LFHC groups respectively. Statistical analysis indicated that there was no relationship between overall performance time and the rate of CHO ingestion during the race, r = -0.41, p = 0.051 (Figure 4.5a). In contrast, performance time was negatively correlated with the volume of CHO (relative to body mass) consumed during the CHO loading period, r = -0.59, p = 0.008 (Figure 4.5b).

Table 4.4. Nutritional intake during the race for the HFLC and LFHC groups.

	HFLC	LFHC
CHO ($g.h^{-1}$)	55.8 ± 33.8*	55.9 ± 26.0*
Protein ($g.h^{-1}$)	1.10 ± 0.72	0.92 ± 0.47
Fat ($g.h^{-1}$)	1.85 ± 1.71	1.51 ± 1.09
Fibre ($g.h^{-1}$)	0.66 ± 0.40	0.73 ± 0.51
Sodium ($g.h^{-1}$)	0.26 ± 0.11	0.31 ± 0.18
Potassium ($g.h^{-1}$)	0.20 ± 0.12	0.20 ± 0.19
Fluid ($l.h^{-1}$)	0.44 ± 0.11	0.52 ± 0.23

* participants CHO intake significantly lower than best practice recommendations of 90 $g.hr^{-1}$, p <0.001

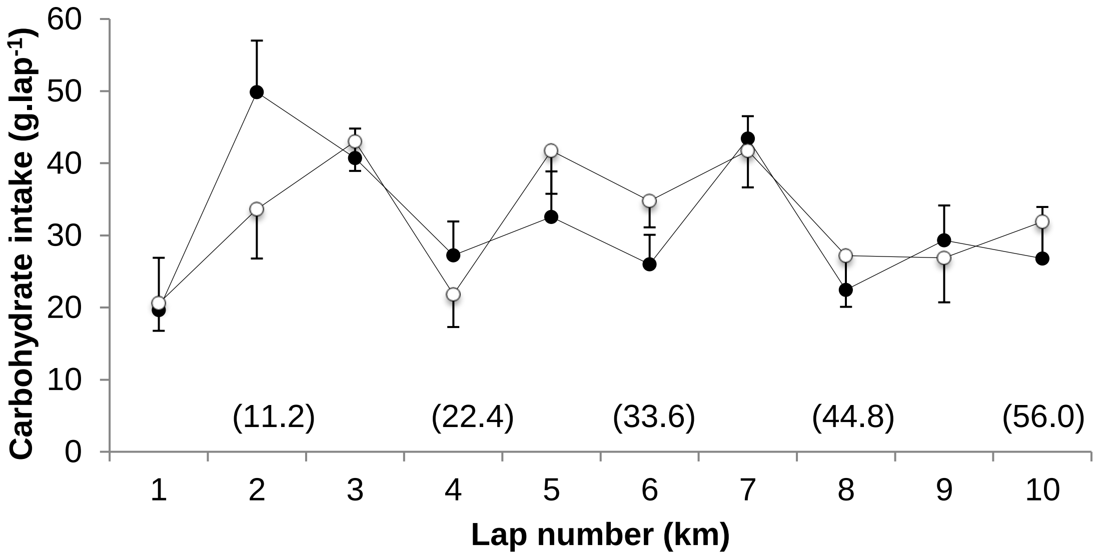
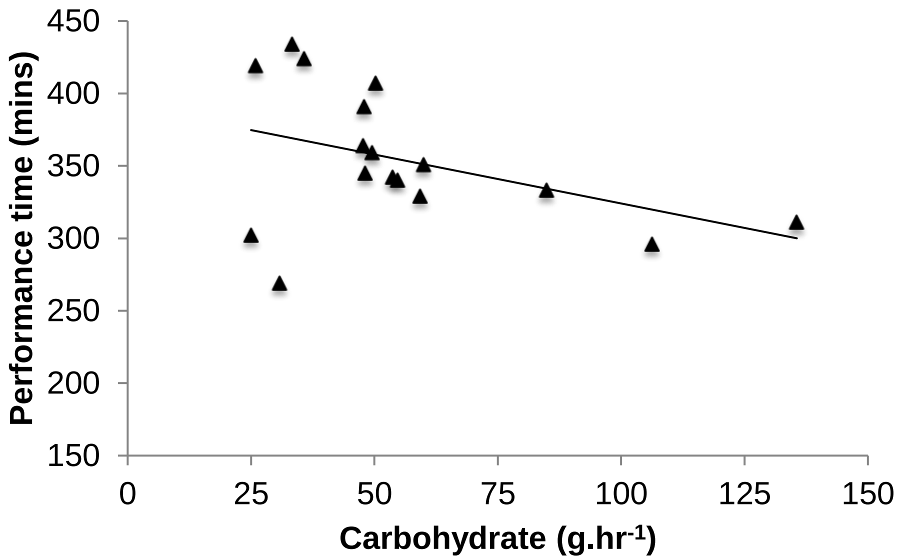


Figure 4.4. Carbohydrate intake per lap for the HFLC (white) and LFHC (black) groups, mean ± standard error mean.

a.



b.

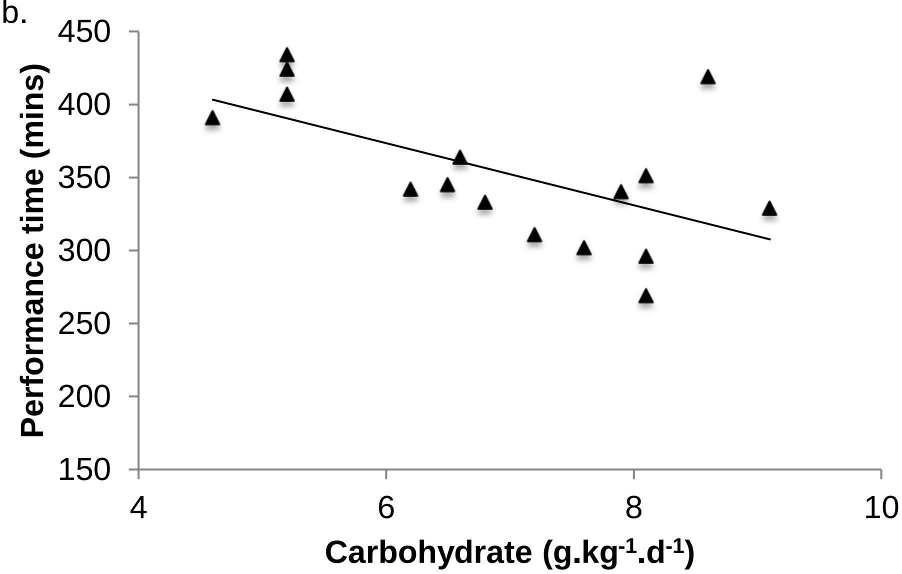


Figure 4.5. Relationship between performance time and CHO intake during the race (a), r = -0.41, p = 0.051 and the CHO loading period (b), r = -0.59 p = 0.008.

4.4.3 Comparison of Glucose and Lactate Between Diet Intervention Groups

The capillary blood samples taken before, during and after the race revealed no significant differences between GT + HFLC and GT + LFHC groups for blood lactate or blood glucose, F (3, 12) = 0.83, p = 0.503, Pillai's Trace = 0.17, ηp^2 = 0.17 and F (3, 8) = 2.04, p = 0.187, Pillai's Trace = 0.43, ηp^2 = 0.43, respectively (Figure 4.6). The capillary blood values for all participants over the course of the race indicated that there was a statistically significant effect of time for both blood lactate, Wilks' Lambda = 0.30, F (2, 14) = 16.3, p <0.001, multivariate η_p^2 = 0.70 and blood glucose, Wilks' Lambda = 0.39, F (2, 10) = 7.99 p = 0.008, multivariate η_p^2 = 0.62. Both blood glucose and blood lactate values where significantly higher at lap 5 and post-race compared to pre-race p <0.05 (Figure 4.6). In contrast, there were no significant differences between lap 5 and post-race for either variable with MD 2.88, p = 0.096, 95% CI -0.40 to 6.18 and 0.68, p = 0.630, 95% CI -0.76 to 2.13 for blood lactate and blood glucose respectively.

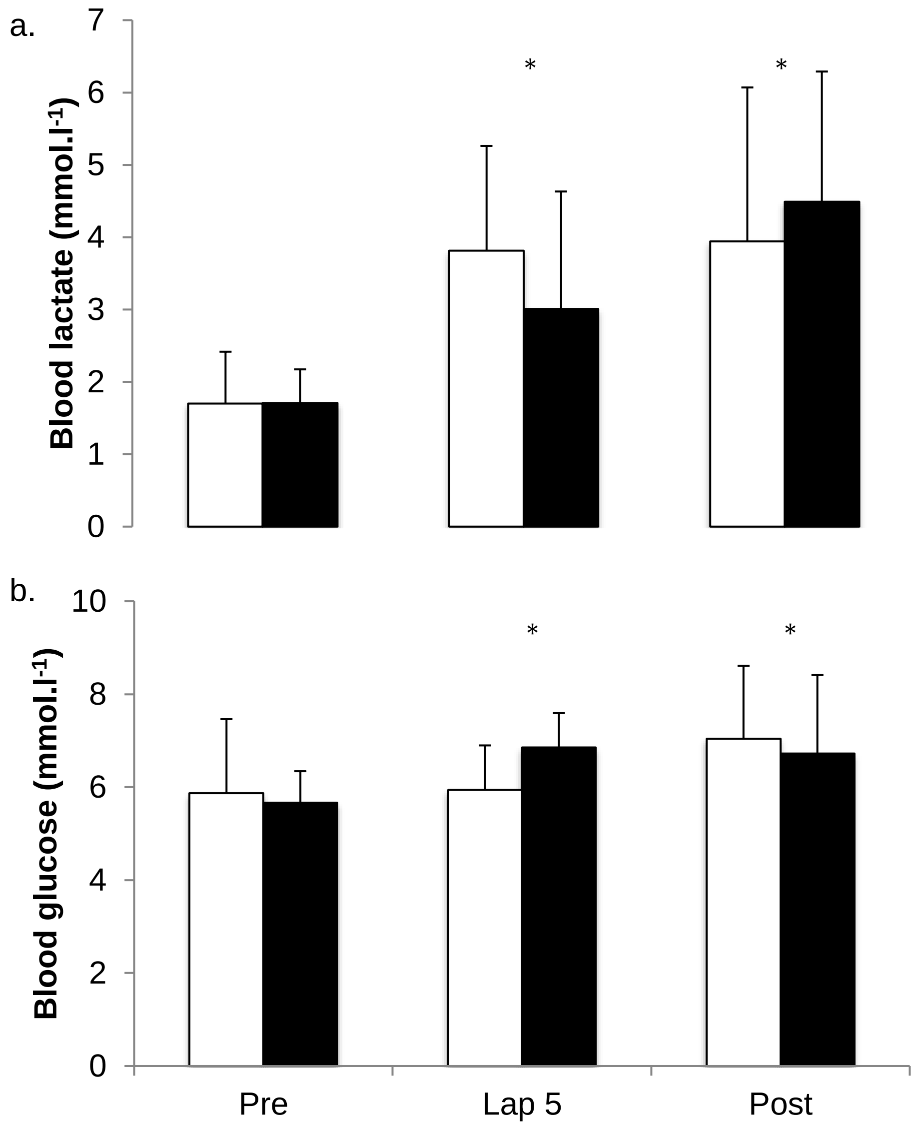


Figure 4.6 Capillary blood lactate (a) and blood glucose (b) values during the race for HFLC (white) and LFHC (black) groups * significantly higher than pre-race, $p < 0.05$.

4.4.4 Incidence of Gastrointestinal Symptoms

The number of participants who experienced at least one GIS at baseline (16, 94.1%) and post-race (16, 94.0%) was extremely high. The highest incidence rates recorded at baseline and post-race were for flatulence and nausea (Figure 4.7), respectively, however, the overall incidence of GIS did not differ between these two time points (Table 4.5), Z -0.92, p = 0.358, r = 0.22. Therefore, the hypothesis that GT would reduce GIS has been rejected. Furthermore, subgroup analysis indicated that there were no differences in incidence rates between participants allocated to the HFLC and the LFHC diet groups at baseline or post-race, U = 22.0, p = 0.171, r = 0.39 and U = 24.0, p = 0.236, r = 0.33, respectively. When the location of symptoms was considered independently, there was a trend for a lower incidence of upper and lower GIS at baseline (58.8% and 64.7%, respectively) compared to post-race (82.4% and 70.6%). Whereas, there was a trend for a higher incidence of systemic GIS at baseline (64.7%) compared to post race (70.6%). The incidence of individual GIS ranged from 12 to 53% at baseline and 0 to 53% post-race.

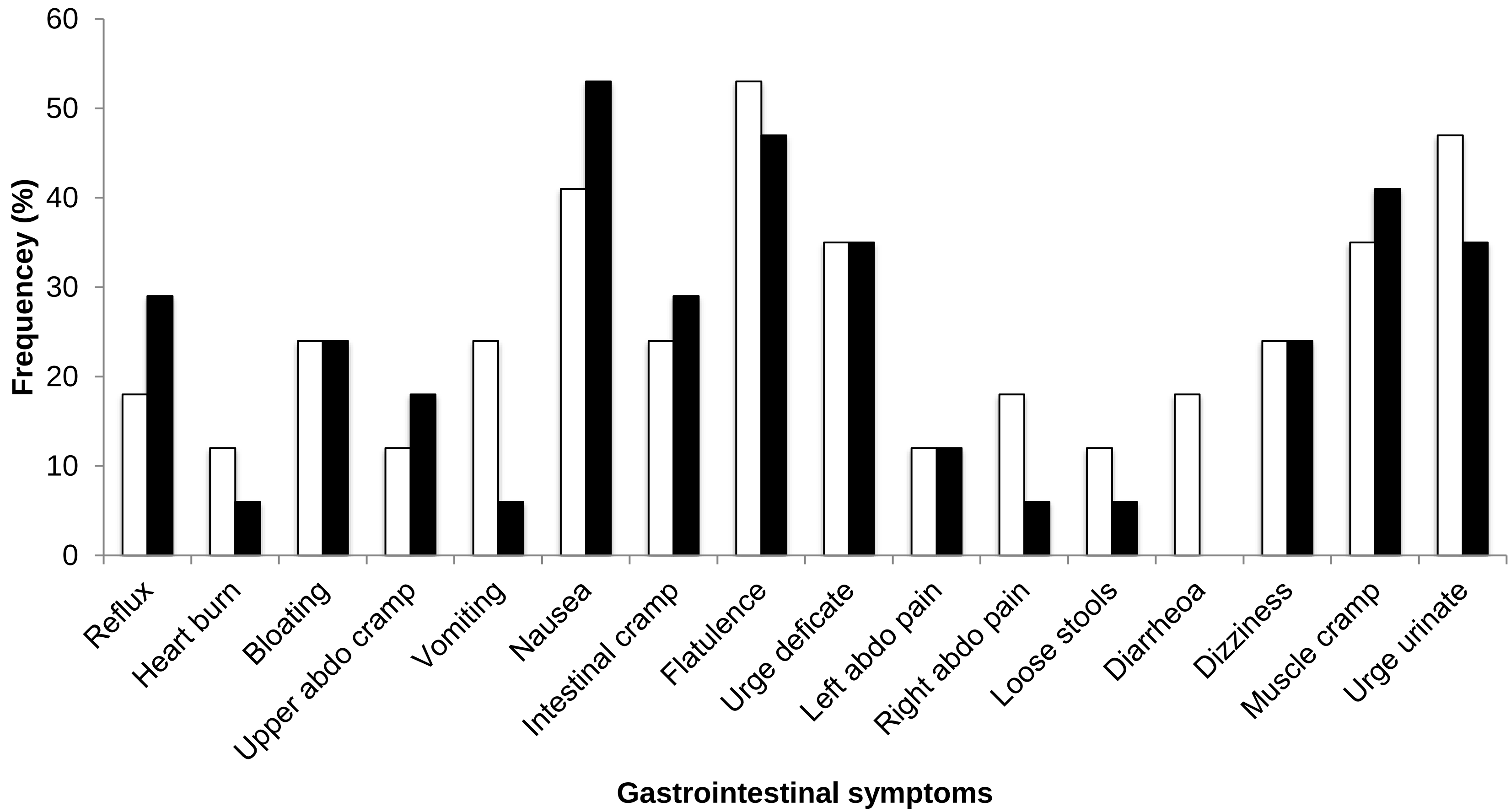


Figure 4.7 Incidence of gastrointestinal symptoms for all participants at baseline (white) and post race (black).

Table 4.5. Incidence and severity of individual GIS for all participants between baseline and the race.

	Baseline (n, %)	**Post race** (n, %)	**Sig** (*p*)
Total			
Incidence of individual symptoms (max 272*)	69 (25)	63 (23)	0.358
Highest severity of symptoms (1-9)	9	9	0.503
Total Nº of symptoms with severity >4	18 (7)	22 (8)	
Upper			
Incidence of individual symptoms (max 102*)	22 (22)	23 (23)	0.887
Highest severity of symptoms (1-9)	7	9	0.158
Total Nº of symptoms with severity >4	7 (7)	9 (9)	
Lower			
Incidence of individual symptoms (max 119*)	29 (24)	23 (19)	0.485
Highest severity of symptoms (1-9)	8	8	0.754
Total Nº of symptoms with severity >4	4 (3)	5 (4)	
Systemic			
Incidence of individual symptoms (max 51*)	18 (26)	17 (25)	0.803
Highest severity of symptoms (1-9)	9	9	0.972
Total Nº of symptoms with severity >4	7 (14)	8 (16)	

* Max = Nº of symptoms within the GIS category x number of participants

4.4.5 Severity of Gastrointestinal Symptoms

The average (*median*) GIS severity ranged between *0* and *2* at baseline and 0 and 1 post-race, however, some GIS (n = 1 and n = 2, at baseline and post-race respectively) were rated as the 'worse as they could be' (9) by individual participants (Table 4.5). In general, there was a very low incidence of severe (>4) GIS (Table 4.5) and there was no significant difference in the incidence of severe symptoms between time points, Z -0.50, p = 0.614, r = 0.12. The GIS most commonly rated as severe were muscle cramps (24%) at baseline and muscle cramps (24%) and nausea (24%) post-race. Subgroup analysis revealed that there was no difference in the severity of individual GIS between participants following the HFLC diet compared to the LFHC diet, except for 'muscle cramps' at baseline (*0.0* ± *0.0* and *2.0* ± *6.0*, respectively), U = 12.0, z = -2.71, p = 0.007, r = 0.67.

4.4.6 Nutritional Intake and Gastrointestinal Symptoms

The rate of CHO intake during the race was 54.6 ± 28.6 $g.h^{-1}$, which despite GT was significantly below best practice recommendations, MD -35.4 $g.hr^{-1}$ t (16) = -4.86, p <0.001, d = 2.51 (95% CI: -49.1 to -19.3), therefore the associated hypothesis has been rejected. Protein and fat was consumed at a rate of 1.0 ± 0.6 $g.h^{-1}$ and 1.6 ± 1.4 $g.h^{-1}$, respectively, however, further analysis was not possible as there are no specific guidelines for consumption during competition in relation to these macronutrients. Fluid was ingested at a rate of 0.48 ± 0.19 $l.h^{-1}$, while the electrolytes, sodium and potassium were consumed at a rate of 0.28 ± 0.15 $mg.h^{-1}$ and 0.24 ± 0.16 $mg.hr^{-1}$. Consequently, BM reduced from 75.9 ± 9.3 kg to 74.0 ± 8.8 kg post-race, indicating an overall BM loss of 1.9 ± 1.4%, which reached statistical significance (Z = -3.21, p <0.001, r = 0.81).

When BM was adjusted for fluid consumed between the two measurements, BM loss increased to 6.8 ± 1.4%. The average urine osmolality and blood sodium values both increased from pre-race (*330* ± *410* $mOsm/kg^{-1}$ and *141.3* ± *2.0* $mEq.l^{-1}$) to post-race (*810* ± *400* $mOsm/kg^{-1}$ and *151.7* ± *11* $mEq.l^{-1}$). However, there was considerable inter-individual variance for these variables (Figure 4.8). Statistical analysis revealed post-race sodium concentration and urine osmolality was significantly elevated, median difference *10.4* mEq.l^{-1}, Z = -2.39, p = 0.017, r = 0.58 and median difference *480* mOsm/kg^{-1}, Z = -3.58, p <0.001, r = 0.86, respectively.

Exploration of the relationship between GIS and the hydration markers (i.e. post-race blood sodium, urine osmolality, BM loss and adjusted BM loss) indicated that there were no significant correlations between variables for the ultra-runners overall, Bonferoni corrected p >0.013. Furthermore, the post-race blood potassium concentration was not correlated with any of the GIS, r_s = -0.37 to 0.42, p = 0.104 to 0.985. After Bonferroni corrections to the p-value it was also found that the rates of nutritional intake (i.e. CHOs, protein, fat, fibre or fluid) during the race were not correlated with any of the GIS, p > 0.001.

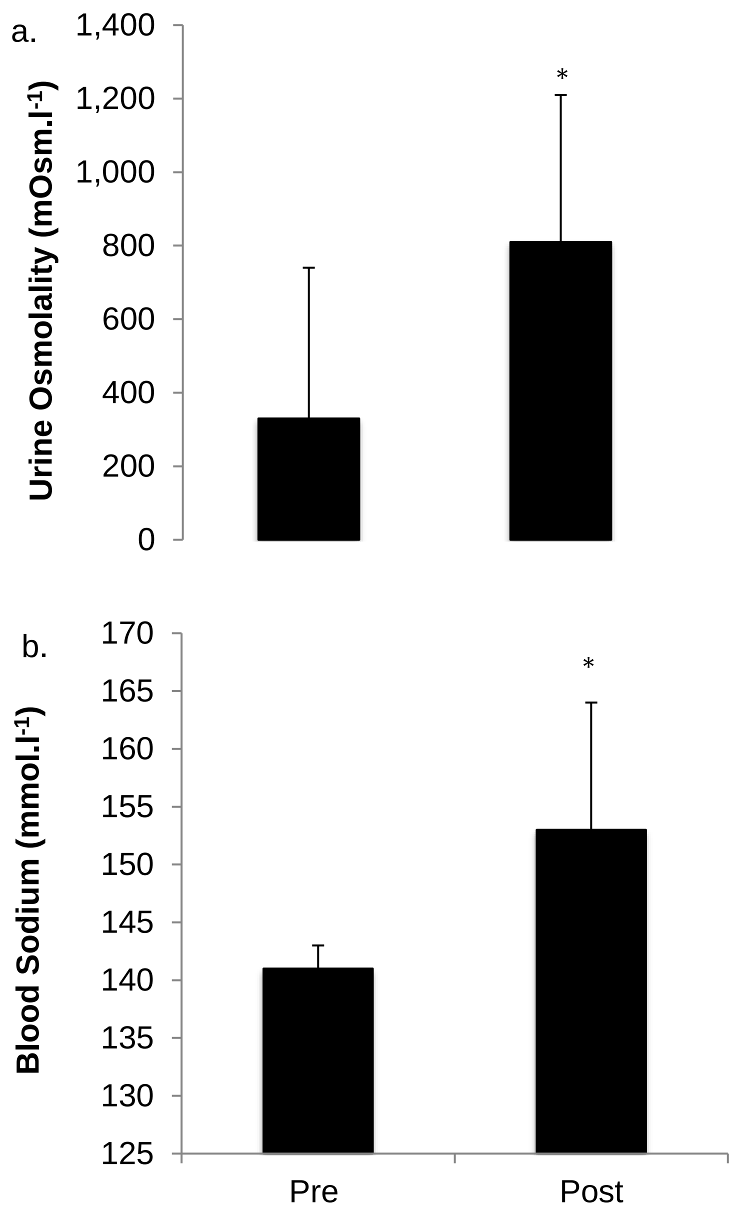


Figure 4.8. Urine osmolality (a) and blood sodium (b) values for before and after the race, median ± interquartile range. *significantly higher, p <0.05.

4.5 Discussion

This is the first ultra-endurance study to employ a multicomponent dietary intervention to address two key barriers to optimal nutritional intake and ultimately performance, namely GIS and fuel availability (Study 2, Chapter 3). This approach was favoured over a single component intervention as it combined dietary practices that are purported to be optimal for prolonged endurance performance (Section 2.3.2), with strategies capable of improving CHO intake (GT, Section 2.5.3) and fuel availability (Section 2.3.1.3). As such, it provided the opportunity to establish whether a HFLC or a LFHC diet was superior for ultra-endurance performance, when athletes were given maximum opportunity to optimise their CHO intake and muscle glycogen levels. Nevertheless, the complexity of this multicomponent intervention presents several challenges to the interpretation of the study findings.

Firstly, the relationship between GIS and nutritional intake is not fully understood (Section 2.5.3). As such, it is possible that any benefits to GIS obtained during the GT period, may have been offset by the athlete's allocated diet or CHO loading immediately prior to the race. The latter is conceivable, given that a high volume of CHO, especially from hypertonic fluids has been observed to increase the risk of GIS during exercise (Horner et al., 2015; Rehrer, et al., 1992; & Saris, 1992). Secondly, the ad-libitum CHO intake may have been moderated by the ingestion of sweet flavoured sports products (rather than GIS), which were provided to athletes to supplement their diet during the CHO loading period. An interview with sports nutrition professionals supporting ultra-endurance athletes noted that flavour fatigue was a common issue, with athletes becoming tired of the same tastes (Burke, 2002). Finally, allowing the athletes to consume a range of different products, rather than a standardised CHO drink or supplement, makes it difficult to interpret the GIS. Gut training is more effective when the CHO consumed during competition matches that consumed while GT (Costa, et al., 2017). However, the aforementioned flavour fatigue may prevent consumption of the recommended rate of CHO (90 $g.hr^{-1}$), if using a single product, despite familiarisation during training.

In contrast to the hypothesis, the primary findings indicate that (i) there was no difference in ultra-endurance performance between GT + HFLC and GT+ LFHC diet when participants CHO loaded and ingested CHO during competition (ii) four weeks of GT failed to reduce the incidence or severity of GIS, and (iii), GT did not enable the ultra-runners to consume CHO at a rate that matches current recommendations for activities lasting >2.5 hr (Thomas et al., 2016).

Participants following the GT + HFLC diet completed the 56 km race in a comparable time to the GT + LFHC participants (353.6 ± 42.8 min and 354.1 ± 54.3 min, respectively). This is in agreement with a previous study that failed to detect a meaningful difference in power output (312 ± 15 and 279 ± 20 W, p = 0.11) between a short term HFLC (69% fat and 16% CHO) and LFHC (70% CHO and 15% fat) intervention when glycogen was restored (Carey et al., 2001). Although, it is noteworthy that during their randomised, crossover study there was a trend for some participants to cover a greater distance during the 1 hr time trial (after a 4 hr preload cycle at 65% of VO_{2max}) in the HFLC trial. This was coupled with an 11% higher power output for the HFLC trial, which they stated was equivalent to a non-significant improvement in performance of 4%.

A similar trend for improved performance was observed after a two week HFLC diet (60% fat and 30% CHO), without CHO restoration during a small study of two male rowers (Robins et al., 2005). Although, both participants covered considerably greater distances (12685 m and 25240 m) during the 24 hr rowing protocol after the HFLC, the low participant numbers prevented statistical analysis and the parallel-crossover design could indicate an order effect. Despite this, it is highly likely that the rowers would rely more heavily on fat oxidation than the current participants and therefore stand to gain more from diet manipulation and fat adaptation protocols. This can be seen from the lower respiratory exchange ratio during the final segment of the 24 hr row (RER 0.81) compared to the latter stages of the 4 hr cycle (RER 0.85) (Carey et al., 2001; Robins et al., 2005).

In the current study, the absolute and relative intensity were comparable across the duration of the race for the GT + HFLC and the GT + LFHC groups. This indicates that the HFLC diet intervention had little impact on the participant's performance, even when glycogen stores were likely to be compromised. Glycogen levels of ~25 $mmol.kg^{-1}$ wet weight have been reported to coincide with exhaustion (Hawley, Schabort, Noakes, & Dennis, 1997). This translates to glycogen stores of 107 $mmol.kg^{-1}$ dry weight, when using the conversion rate suggested by Van Hall, Shirreffs, and Calbet (2000) (i.e. 1.4 $mmol.kg^{-1}$ dry weight, being equivalent to 6 $mmol.kg^{-1}$ wet weight). Slightly lower post exercise muscle glycogen concentration of 55 $mmol.kg^{-1}$ and 96 $mmol.kg^{-1}$ dry weight have been observed after <3 hr cycling at ~60% peak power output (Burke et al., 2000), despite CHO ingestion and high CHO intake (6 and 9 $g.kg^{-1}$, respectively) in the day before their exercise protocol. Therefore, it is likely that the post exercise muscle glycogen concentration of the participants in the current study may have been compromised even further, given the longer duration (~5 hr 50 min), but comparable exercise intensity and CHO intake.

It is worth noting that the GT + HFLC group consumed significantly less CHO during the CHO loading period, however, this may have been offset by the potential glycogen sparing effect of fat adaptation. As such, the absence of an effect on performance in this study may be in part explained by the insufficient CHO loading of the GT + HFLC group, however, it could also reflect the difficulty in measuring performance in matched groups. The combination of the relatively large number of participants taking part and the challenges associated with the race environment in this study, measurement of fat and CHO oxidation rates was not possible. As such, it is not possible to confirm whether the GT + HFLC diet intervention resulted in increases in fat oxidation. Furthermore, it was not possible to obtain muscle biopsies to confirm muscle glycogen supercompensation. Previous studies have reported increased fat oxidation rates (Burke, 2015) and muscle glycogen concentration (Burke, et al., 2000) with similar diet manipulation, however, there was an element of variability in the level of compliance with these components of the dietary intervention.

A secondary finding of this study was that the incidence of GIS (94.1%) was comparable to the high rates observed by Jeukendrup et al. (1999) and Stuempfle & Hoffman, (2015), despite the considerably shorter duration. In the latter study, ultra-runners competing in a 161 km race, lasting ~24 h reported that 96% of participants experienced at least one symptom. Similar to the current findings, the symptom with the highest incidence was nausea, which effected 86% of participants overall, with the majority experienced in the final two stages of the 161 km race (Stuempfle & Hoffman, 2015). Given that Hoffman & Fogard (2011) observed slower race times (p = 0.008) and difficulty making cut-off times (p = 0.008) for those experiencing nausea, this could have had negative implications for athletic performance in symptomatic athletes in the current study. In contrast, higher incidences of urge to urinate have been observed in ultra-endurance triathletes (Jeukendrup et al., 1999). Suggesting that the mode of physical activity may be an influential factor in the GIS profile of ultra-endurance athletes. Although the incidence of GIS during the race was high, the average GIS severity reported here was low and therefore unlikely to have a negative impact on performance. Notably, there was considerable inter-individual variability in the severity of symptoms, which was also consistent with previous findings (Costa et al., 2016; Ter Steege et al., 2008). In earlier studies, severe GIS's have for some athletes resulted in race abandonment (Jeukendrup et al., 1999; Ter Steege et al., 2008). None of the participants with severe symptoms in the current study dropped out of the race, however, it is possible that their performance was impaired.

In contrast to the hypothesis, the GT protocol completed by athletes in the current study appeared to have little impact on the severity of GIS during the race. Overall, there were no significant differences in GIS between the prolonged training run (>3 hr) at baseline and the 56 km race. Although, it should be noted that the average GIS at baseline was low (severity of *0.0* to *2.0*) and the only symptom to increase above pre-race values was nausea (p <0.008). This indicates that there was little scope for improvement in this sample group. Furthermore, symptom incidence is purported to increase with exercise duration (Pfeiffer et al., 2012), given that the duration of both the baseline run and the race varied between runners, direct comparison of GIS may impact on the credibility of these findings. In addition, the sensitivity and the test-retest reliability of the tool used to quantify GIS was unknown (Section 2.5.3.2), therefore it may not be capable of detecting subtle changes in symptom severity.

In contrast to this study findings, a group of recreational ultra-endurance runners (*n* = 25) who experienced moderate (100%) and severe (52%) symptoms prior to GT, reported significant improvements in all GIS after specific CHO training (Costa et al., 2016), which allowed them to better tolerate high rates of CHO intake. When these ultra-endurance runners consumed other sources of CHO that they had not trained with, improvements were seen in upper GIS but not lower GIS. This finding suggests that adaptations to GT were somewhat specific to the food ingested and therefore athletes are likely to benefit from training with the foods they plan to consume during competition in order to reduce their risk of GIS. This is likely to be particularly important for ultra-endurance athletes with a history of severe GIS.

Despite specific GT and the high availability of a variety of familiar sources of CHO (i.e. drinks, foods and sports products) at regular intervals (~2.8 km) during the race, participants consumed significantly lower rates of CHO (54.6 $kg.h^{-1}$) than recommended (90 $g.hr^{-1}$) (Burke et al., 2011). This is in contrast to the hypothesis. The inability to meet the recommended CHO intake during competition, but not during the final two weeks of the GT period, suggests that the competitive environment may be a mediating factor for increased GIS and reduced CHO intake. However, further research is required to gain a detailed understanding of the barriers and facilitators that influence food choice during competition (Study 4, Chapter 5). The suboptimal and variable rates of CHO observed in the current study are consistent with previous findings in race conditions (Costa, Gill, Hankey, Wright, & Marczak, 2014; Stellingwerff, 2016; & Wardenaar et al., 2015). As an example, Costa et al. (2014) observed recreational ultra-runners (*n* = 25) competing in a 24 hr race and estimated their CHO intake to be 37 ± 24 $g.h^{-1}$, which is considerably lower than best practice recommendations and the current studies participants. Higher rates were self-reported by three elite ultra-marathon runners (71 ± 20 $g.h^{-1}$) during a 100 mile race, but still fell below current recommendations for most runners.

Wardenaar et al., (2015) compared the self-reported nutritional intake of runners during a 60 km race to specific CHO targets and purported that 75% of runners consumed <60 $g.h^{-1}$ and only 2.4 % exceeded the CHO target of 90 $g.h^{-1}$. In the same study, the nutritional intake of four runners during a 120 km race indicated considerable intra-runner and inter-runner variability in CHO intake. The average intake during the race for individual runners ranged from 31 to 69 $g.h^{-1}$, while the lowest and highest volume of CHO for all runners in a single hour ranged from 8 to 39 g and 57 to 135g, respectively. This indicates that participants do not follow a standardised CHO plan as recommended by the consensus guidance for nutrition and performance (Thomas et al., 2016). Furthermore, moderate correlations between BM and CHO oxidation (r = 0.51, p <0.001) during submaximal running (Costa, et al., 2017) suggest that an individualised CHO recommendation may be more appropriate. An interesting approach to indivdialised CHO intake is the model developed by Pruitt and Hill (2017), which uses the altitude, terrain and distance of a race to predict the minimum completion time and carbohydrate required to achieve this time.

The consequences of suboptimal nutritional intake can be impaired performance that in some cases results in failure to complete an ultra-endurance race (Stuempfle, Hoffman, Weschler, Rogers, & Hew-Butler, 2011). Many plausible explanations for suboptimal nutritional intake have been implied in the literature. Firstly, the positive, albeit weak relationship between nutritional knowledge and dietary intake reported by Spronk, (2014) suggests that poor nutritional knowledge may be a barrier to optimal intake. However, the current athletes were provided with specific dietary education to address gaps in their knowledge and supporting information and nutrition products to aid dietary compliance in preparation for and during the race.

Secondly, GIS have been implicated as a potential cause of inadequate nutritional intake, with runners experiencing GIS during a multi-stage ultra-marathon consuming less CHO (Costa et al., 2016). Although, this pattern of compromised CHO intake was not observed during a 24 hr race (Costa et al., 2016). An earlier study of marathon runners, cyclists and triathletes found a weak but positive relationship between CHO intake and both nausea and flatulence in triathletes competing in full and half-Ironman distance events (Pfeiffer et al., 2012). The authors concluded that CHO intake may therefore be a risk factor for GIS. As such, it is possible that individuals with a history of GIS may avoid consuming high volumes of CHO, to minimise their risk.

Although it is noteworthy that there was no difference in the volume of CHO consumed between those with severe GIS and those with mild or no GIS and some athletes managed to consume ~120 $g.hr^{-1}$ of CHO. Furthermore, Pfeiffer et al. (2012) had failed to adjust the *p*-value for the number of variables they investigated. In the current study, GIS were not related to nutritional intake or markers of hydration status. This may in part be explained by the relatively low severity of symptoms, making it difficult to detect meaningful relationships between these variables for this group of ultra-endurance runners. Together with findings in the existing literature, these results indicate that the relationship between GIS and nutritional intakes remains equivocal.

Finally, the brief reflections of five ultra-runners after a multi-stage race have provided some insight into the range of factors that can influence food intake during competition (McCubbin et al., 2016). These included reduced appetite, food/drink temperature, taste fatigue, product weight and difficulty consuming specific products. This study suggests that the barriers to optimal nutritional intake are multifaceted. This is consistent with the current observations as participants rated several factors as highly important to their food choices, including quality, food characteristics, GIS and energy needs. Consequently, future studies exploring in detail the complexity of food choice for competition may be of interest to nutrition professionals who support ultra-endurance athletes with their race nutrition strategies (Study 4, Chapter 5).

4.6 Conclusion

Gastrointestinal symptoms have previously been reported to have a negative impact on nutritional intake and performance. Furthermore, suboptimal nutritional intake commonly reported before and during ultra-endurance running, reduces endogenous and exogenous CHO availability. Thereby increasing reliance on fat oxidation especially in the later stages of ultra-endurance competition. The multicomponent nutritional strategy employed during this study provided an ideal opportunity to address the main challenges to optimal nutritional intake (reported in Chapter 3) and enhance fuel availability as follows; (i) GT training to improve tolerance to high rates of CHO during exercise; (ii) HFLC or LFHC diet to enhance fuel oxidation (iii) CHO loading to promote supercompensation of muscle glycogen stores (iv) race environment that provided ample opportunity to consume familiar CHO.

Despite this, there were no meaningful improvements in GIS after four weeks GT, however the absence of an increase in GIS during the race, which was longer than the exercise performed to obtain baseline GIS, may imply a slight improvement. Furthermore, CHO intake remained significantly below current recommendations. In the absence of high rates of CHO intake, it may have been anticipated that increased fat oxidation, typically observed with a short-term HFLC diet may have been more beneficial to performance. However, this was not observed during the 56 km race, possibly because the race duration was not sufficient to tax the glycogen stores when athletes consumed ~55 $g.hr^{-1}$. Therefore, future multi-component studies should be conducted during races likely to be more reliant on fat oxidation (i.e. 12 and 24 hr races) with athletes most likely to benefit (i.e. homogenous group of ultra-runners who experience severe GIS). This study provided evidence that athletes self-select CHO at a rate that is tolerable for them, while they attempt to consume sufficient energy to enable them to complete the race. To explore this further, interviews with ultra-endurance athletes are needed to capture the complexity of the food choice process (Study 4, Chapter 5).

Chapter 5: Exploration of Ultra-Endurance Runner's Experiences of Making Food Choices During Competition

5.1 Study 4: Exploration of Ultra-Endurance Runner's Experiences of Making Food Choices During Competition

5.2 Introduction

Food choices can be influenced by multiple factors that may prevent athletes from meeting their nutritional needs, with potential consequences for training adaptations and performance (Study 2, Chapter 3). The previous multi-component study (Chapter 4), which was designed to overcome the main challenges to optimal nutritional intake, did not facilitate the recommended rate of CHO intake. This suggests that the processes involved in making food selections during competition are more complex. To date, a small body of research has explored how athletes consider their food choices and make their food selections across different settings. Researchers in this domain have explored motives that drive food choice (Long, Perry, Unruh, Lewis, & Stanek-Krogstrand, 2011), barriers to optimal nutrition (Heaney, O'Connor, Naughton, & Gifford, 2008) and the processes involved in selecting individual foods (Smart & Bisogni, 2001). The latter, offers opportunity to gain a greater understanding of the complexity of the athlete’s decision-making process, when faced with multiple or competing influencing factors.

Research conducted by Smart & Bisogni (2001) added to existing literature, which conceptualised the processes involved in a single food choice (Furst, Connors, Bisogni, Sobal, and Falk, 1996) (Section 2.5.2.1). The original model, verified and elaborated a number of times (Sobal & Bisogni, 2009) contains three core elements (i) life course, (ii) influences, and (iii) personal systems that combine to shape the food choices of individuals. The life course was reported to provide the foundations of food choice, generated from past experiences, current involvements and anticipated future events (Furst et al., 1996). As such, food choices are shaped by an individual's unique experience of social, cultural and physical environments. With exposure to new environments providing the stimulus for changing their food choices (Devine, Connors, Bisogni, & Sobal, 1998). In an athletic population, some early experiences of foods have been noted to persist into later life, while new social and personal roles relating to athletic performance have acted as transition points that resulted in changes to food choice (Smart & Bisogni, 2001). These transitions were prompted by coaches' expectations for body composition, discussions with peers and their own experience of eating and performing, highlighting the influence of the social and physical environment. Similar transitions are likely to be prompted by peers in ultra-endurance populations, given that 73% of athletes who participated in study 1 (Chapter 3), obtained nutritional information from other athletes.

Through an individual's life course experiences, an individual is influenced by a number of factors (Furst et al., 1996). Common factors have been reported across general and athletic populations such as taste (Long et al., 2011), health (Turner-Mcgrievy, Moore, & Barr-Anderson, 2016) and convenience (Smart & Bisogni, 2001). Although, the meanings attached to these factors appears to be unique to the population studied and time period (Smart & Bisogni, 2001). In the final element of the food choice model, Furst et al. (1996) noted how individuals managed the interaction and conflict between the multiple factors that influenced their food choice (Connors, Bisogni, Sobal, & Devine, 2001). This consisted of two components, firstly, the conscious value negotiation process, which involved prioritisation of conflicting food choice values, in the context of the environment or situation (Connors et al., 2001). Secondly, the unconscious strategies individuals employed to simplify routine choices in familiar surroundings (Connors et al., 2001; Furst et al., 1996). Given the potential conflict between the multiple factors that influence the food choices of ultra-endurance athletes during competition (observed in Study 2, Chapter 3), negotiation is likely to be a core component of food selection process for these athletes.

Earlier work (Study 2, Chapter 3) may be used to provide sports nutrition practitioners and those involved in food provisions with an insight into the motives and barriers to optimal nutritional intake. However, it is limited to a snapshot of the factors that influence an ultra-endurance athlete’s food choice, and does not capture the complexity of the food choice process. To date the research in this area appears to have focused on the habitual food choices of the general population and athletes engaged in team sports. Given that physical demands and nutritional requirements are unique to the sporting context (Thomas, Erdman, & Burke, 2016), research is required to explore the processes involved in food selection, within a competitive ultra-endurance environment. Therefore the aim of this study was to explore the factors that influence food choices during an ultra-endurance race, and the processes involved in making individual food selections.

5.3 Methods

5.3.1 Methodological Approach

An inductive qualitative methodology was employed to explore the factors that influenced the food choices of ultra-endurance runners, during competition. This approach allowed the ultra-runners to provide detailed accounts of the factors that influenced their food choices from their lived experience (Braun & Clarke, 2013) of making food selections during a 56 km race. It also enabled them to capture the complexity of the food choice process as they progressed through the race. Notably, all of the ultra-runners who took part in the race entered as participants for a nutrition intervention study, as described in Chapter 4. In summary, this involved a period of dietary manipulation in preparation for the race, along with standardised education and the availability of CHO rich foods and fluids stationed every 2.8 km. Despite this, post-race dietary analysis revealed CHO intake (~56 $g.h^{-1}$) was significantly below the optimum CHO recommendations ($90g.h^{-1}$). While elements of the nutrition intervention were unique to the requirements of the preceding study, the suboptimal nutritional intake was comparable to previous research. As such, this research race design provided an ideal opportunity to explore the ultra-runners experiences of making food choices under competitive conditions, with a view to gaining a better understanding of the barriers to optimal intake.

5.3.2 Participants

A convenience sub-sample of 14 experienced, recreational ultra-runners who completed the nutrition intervention study were recruited for this study, which was approved by the University Research Ethics Committee. Interested ultra-runners provided informed consent face to face after a post-race meal. In general, the sub-sample was comparable for gender, age, body composition, experience, performance and habitual diet (Table 5.1), providing evidence of transferability to the population taking part in the race (Schwandt, 2001).

Table 5.1 Ultra-runner population and sub-sample characteristics (mean ± standard deviation).

		All runners	Interviewed
Gender	Male	16	13
	Female	1	1
Age (years)		41.9 ± 4.8	41.8 ± 4.5
Body composition	Body fat (%)	18.3 ± 6.9	18.8 ± 7.3
	Weight (kg)	77.3 ± 10.9	75.0 ± 10.0
	Height (m)	1.77 ± 0.07	1.76 ± 0.06
VO_{2peak} (ml.kg^{-1})		52.7 ± 7.9	52.9 ± 8.2
Performance (mins)		355 ± 47.4	346.9 ± 46.1
No of marathons		5.2 ± 2.4	5.4 ± 2.3
Habitual diet	No restrictions	15	13
	Vegetarian	2	1
Preparation diet	HFLC	8	8
	LFHC	9	6

BMI = body mass index, HFLC = high fat low CHO diet, LFHC = low fat high CHO diet.

5.3.3 Data Collection

On completion of the race, all ultra-runners completed an ULTRA-FCQ, which was designed to explore the factors influencing the food choice of ultra-endurance athletes during training and competition (Chapter 3). This provided quantitative data to offer support in relation to the credibility and confirmability of the qualitative data, via triangulation (Shenton, 2004). Shortly after, the ultra-runners engaged in face-to-face interviews with an experienced researcher, who had not been involved in the preceding dietary intervention study. The independence of this interviewer was emphasised to all ultra-runners to encourage honest accounts of the influences on their food choices (Shenton, 2004), rather than responses that may be perceived as desirable (i.e. the influence of nutrition education provided by the researcher in the preceding diet intervention study). Furthermore, completing the interviews soon after the race allowed ultra-runners to recount detailed information about the factors that influenced their food choices, with limited susceptibility to memory or recall bias (Coughlin, 1990).

Interviews took place in a private room near to the finish line and they were audio recorded and later transcribed verbatim. The semi-structured interview schedule was developed from existing literature and theories of the food choice process (Furst et al., 1996; Smart & Bisogni, 2001). Each interview lasted ~10 mins and covered three key aspects (i) individual factors that influenced food choice, (ii) the negotiations involved in balancing dissimilar driving factors and (iii) the trends and transitions in food choice related to their personal experiences. A combination of explanatory probes (i.e. Why is that? How can you explain that? Was there a particular reason for that?) and clarification probes (i.e. what do you mean by that? Correct me if I'm wrong, but did you mean…..?, where they equally as important?) were employed. Firstly to capture explanations (Ritchie, Lewis, McNaughton Nicholls, & Ormston, 2014) for the decisions involved in the negotiation element of the food choice process (Furst et al., 1996) and secondly as an immediate form of member checking (Shenton, 2004). Each interview was concluded once the scheduled interview questions and probes failed to produce any new information, however, all ultra-runners had the opportunity to add any further comments in relation to the factors influencing their food choices for the race prior to termination of the interview recording.

5.3.4 Data Analysis

Orthographic transcription of the audio recordings was completed by the author to produce an accurate record of the interviews (Braun and Clark, 2013), while allowing familiarisation with the data as part of the analysis process. The resultant transcript was checked against the audio recordings before the author immersed herself in the full data corpus. Subsequently, the six-phase approach to thematic analysis as described by Braun and Clarke (2006) was used to facilitate extraction of themes from the data corpus. Patterns and meanings were actively sort throughout repeated readings of each data set. Interesting features and patterns in the data were used to generate the initial codes. Individual codes were grouped together to establish candidate themes. A number of techniques where employed during the identification of candidate themes, this included looking for repetitions, analogies, transitions, similarities and differences within and across data sets (Ryan & Bernard, 2003). These themes were reviewed against the original transcripts to ensure their contextual compatibility across the data corpus. The revised themes and codes were triangulated against the quantitative food choice data obtained from ULTRA-FCQ and assessed for congruence with existing theory relating to food choice, prior to producing the final report. This report was scrutinised by the interviewer and the thesis supervisors, resulting in a further refinement and the inclusion of negative case analysis (Lincoln & Guba 1985).

5.4 Results

5.4.1 Refinement of the Themes

The overarching themes extracted from the data corpus (Figure 5.1a) were refined after consideration of the quantitative data and existing theory surrounding food choice and the food choice process (Figure 5.1b). Firstly, triangulation was used to compare the interview themes with the ULTRA-FCQ. During this process it became apparent that the quantitative questionnaire was unable to account for influential factors that represented unique aspects of the event, such as the research tasks. Therefore, the event factors could not be verified. In contrast, the ULTRA-FCQ was able to provide supporting evidence for the food factors and individual factors, with the latter re-labelled ‘physiological factors’ as part of this refinement process. The ULTRA-FCQ also provided supporting evidence for the most pervasive values and beliefs, which were initially considered to be features of the original themes. The importance placed on values and beliefs within the ULTRA-FCQ and interview data provided support for their elevation to a sub-theme, under the theme ‘personal factors’.

Secondly, while consulting existing food choice theory (Bisogni, Jastran, Shen, & Devine, 2005; Devine, 2005; Furst et al., 1996), the strength and features of each sub-theme were reviewed in sequence. A key observation during this reflective period was the dominance of current over past experiences at key time points within the context of the race. This was a common feature of each ultra-runner's transcript, with factors influencing food choice shifting over the course of the race. This was comparable to the temporal framework of the life-course perspective, which has been regarded as an integral component of the well-established food choice process (Devine, 2005). Therefore, it was deemed that the initial representation of the data did not capture the dominant role of the ultra-runner's experiences when making food choices. Furthermore, it failed to illustrate the original contribution that the current research provided in relation to existing theory of the food choice process. Together this two-staged process of theme refinement provided support for the revised schematic of the data, specifically the re-organisation of the event factors and the features of the themes.

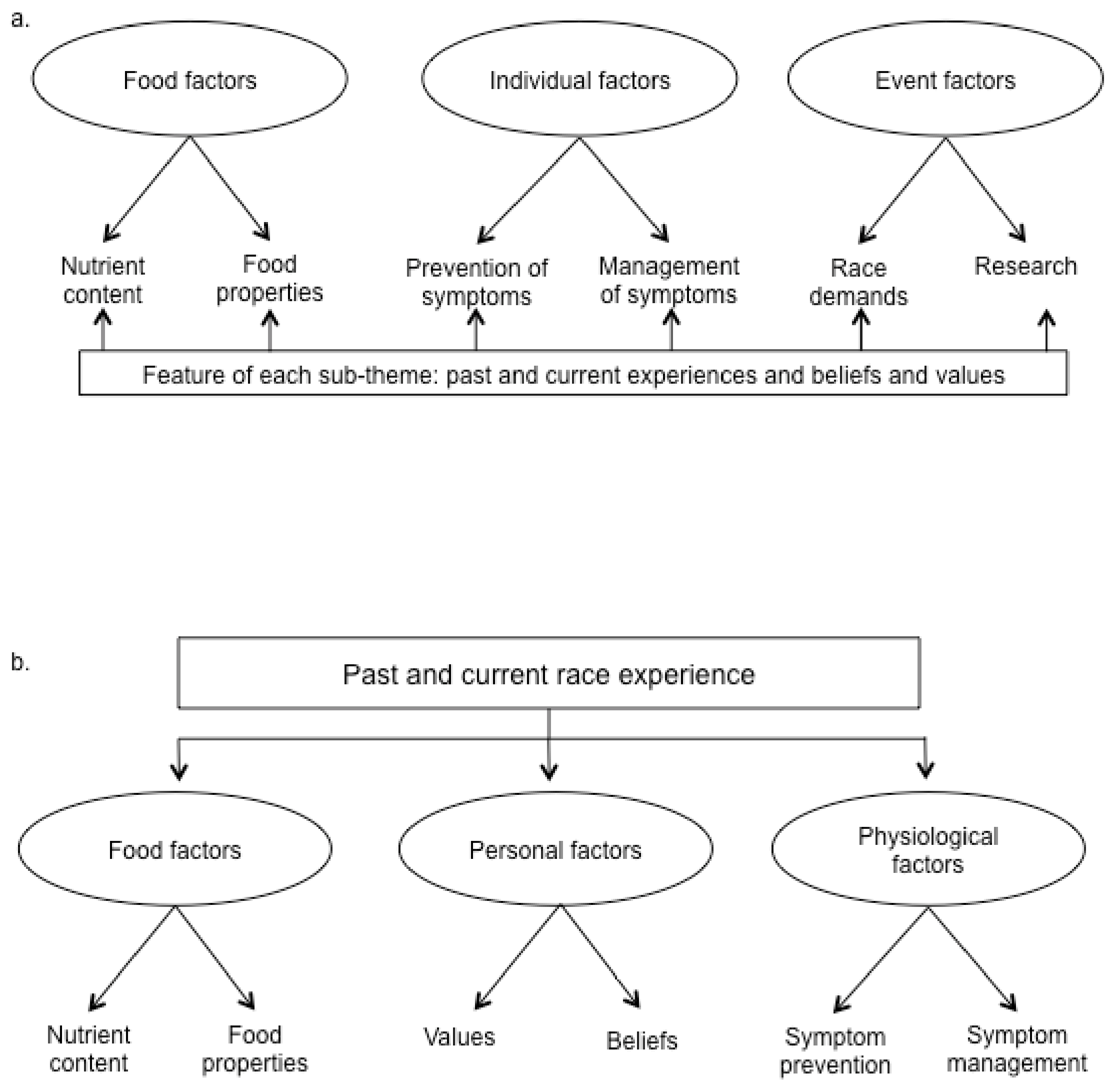


Figure 5.1. Schematic representation of the themes before (a) and after (b) triangulation with the quantitative data and consideration of existing food choice theory.

The three overarching themes extracted from the refinement process were (i) food factors, (ii) physiological factors and (iii) personal factors, each containing two sub-factors. In-depth analysis revealed that there was considerable interaction between overarching factors and the sub-factors within them, with often ultra-runners balancing two or more drivers of food choice at specific time points. This process involved an element of cognitive and subconscious decision-making. In addition, the factors that influenced food choices evolved over the duration of the race, with ultra-runners interpreting their influencing factors in the context of their past and current experiences of training for and competing in distance running events. To illustrate each theme and the complex interaction between factors as the race evolved, extracts from the transcripts are presented using pseudonyms and the ultra-runner's race finishing time to add an element of context. The meaning behind the factors that influenced the food choices of ultra-runners have been interpreted in relation to the author's specialist's sports nutrition knowledge and experience as a long distance runner. This approach is believed to facilitate data analysis when participants use language familiar to the population being studied (Berger, 2013), enabling the researcher to understand implied content.

5.4.2 Past and Current Experiences of Distance Running Events

The significance of the past and current experiences of distance running to the factors that influenced food choices throughout the race is illustrated in Figure 5.2. The dominance of the current experiences as the race progressed is illustrated by the thickness of the vertical arrows in the mid to latter stages of the race. The narrow vertical arrow in the early stage of the race reflects that just two ultra-runners reported the influence of current experiences at that stage of the race. Oliver [7 h 15 m] who experienced 'fullness' and felt a 'little bit sick' from the volume of food consumed at he pre-event meal and Ivan [5 h 45 m] who was feeling 'great' in the first couple of laps. Both ultra-runners reported altering their food choices accordingly. Interestingly, some ultra-runners described how they resisted cues to stop eating as the race progressed, ‘like most ultras you have to make yourself eat…. you don’t want much later’ [Max, 6 h 31 m]. This implied that ultra-runners were also considering anticipated future experiences as they made their food choices.

The interaction between two or more factors during the race also evolved with more emphasis on cognitive decision-making in the latter stages of the race. This mainly reflected current experiences acting as trigger points to alter their food choice. Trigger points represented changes to their sensory preferences ‘too sweet’ ‘I was craving’, energy levels ‘flagging a bit’ ‘I had an energy dip’, and other physiological symptoms ‘a little bit dizzy’ ‘by the end of the 2nd hour I felt pretty sick’. On occasion these triggers were unfamiliar ‘it was hard to get the flapjack down, ordinarily I could eat flapjack all day’, or produced conflicting cues, resulting in a more conscious effort to problem solve when deciding what food to select. Ultra-runners who employed heuristic cues, focusing on ‘familiar’ foods that reflected their preferred textures or tastes simplified the decision-making process. Barry [4 h 56 m] explained how this allowed him to keep his mind focused on racing ‘rather than worrying about choice’. This implies that this ultra-runner was concerned that a conscious decision-making process to food choice may have inadvertently impeded his performance.

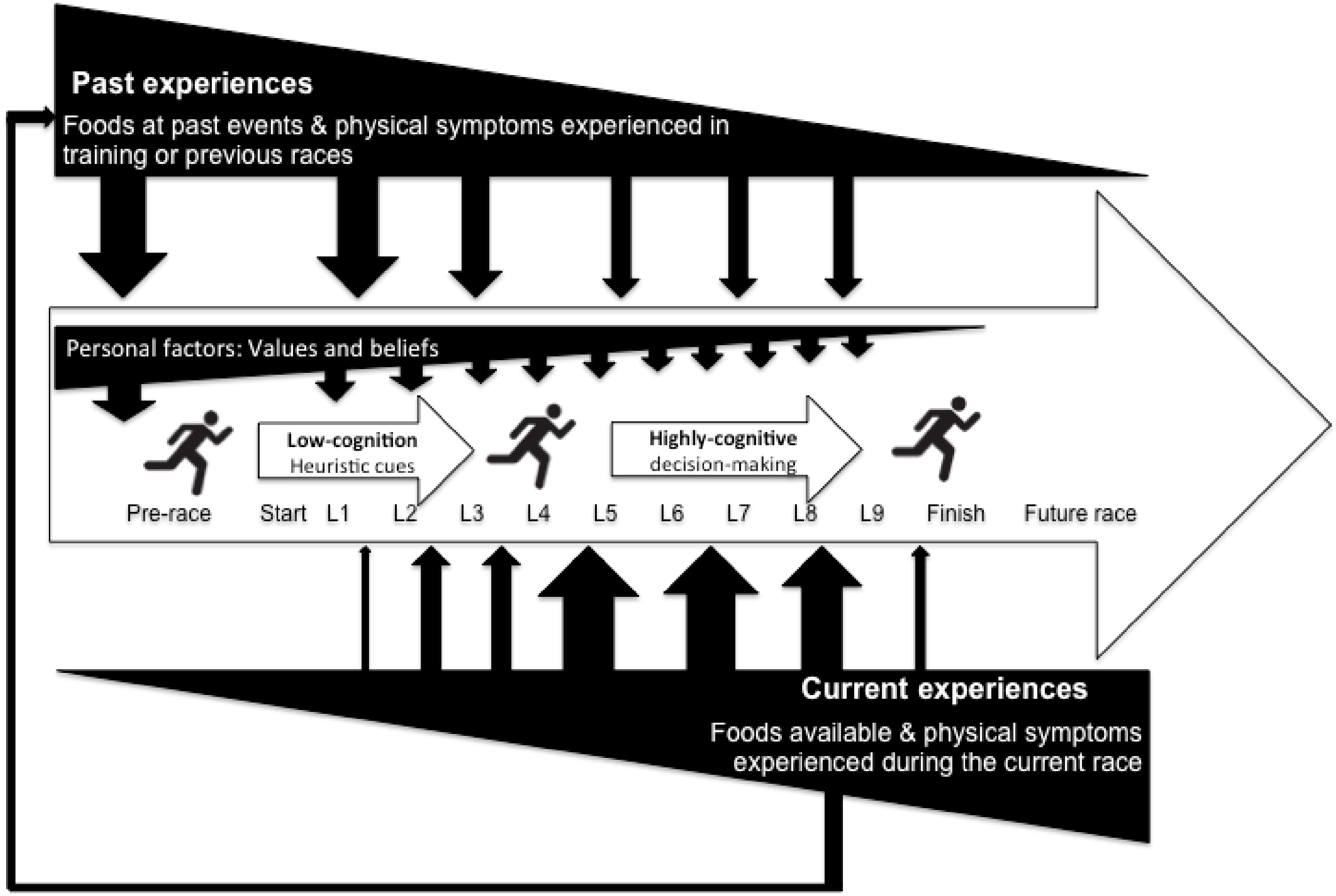


Figure 5.2. The evolving personal food system influencing food choice during the race.

5.4.3 Food Factors

Throughout the race, ultra-runners reported making food choices based on their past knowledge of the nutritional composition, focusing on the CHO, sodium (Na), fluid and fat content of specific items. In addition, they reflected on their past and current experiences of the unique properties of the foods and drinks available, commenting on their flavour, texture, packaging, size and shape. Although often discussed in isolation, many ultra-runners made reference to food factors in relation to their unique physiological and personal factors, providing evidence of the interconnectedness of these themes. At times these factors acted as conflicting stimuli, requiring ultra-runners to engage in active decision-making before making their food or drink selection.

5.4.3.1 Nutritional Composition

Many ultra-runners discussed how they selected items for their higher nutrient or fluid content with statements such as ‘I know it’s got more carbs in’ [Eddie 5h 11 m] and ‘(isogels have) got a lot more water in’ [Jack, 5 h 51 m]. Some explicitly applied the nutrient information to their perceived requirements for ‘sodium’ and ‘fluid’, based on their past experiences of how they respond to the demand of ultra-endurance running. Eddie [5 h 11 m], Barry [4 h 56 m] and Chris [5 h 02 m] made similar statements that illustrated this ‘I know I am a fairly heavy sweater’, ‘I do sweat quite a lot’, and ‘I took a few salted crisps because I knew later on in the race I could potentially cramp up’. This provided evidence of the interaction between the food and physiological factors. A less obvious application of the nutrition information was associated with their desire for regular CHO intake. One ultra-runner specifically referred to his nutritional intake in comparison to his target of 90 $g.hr^{-1}$, which reflects the maximum oxidation rate of multi-transport CHOs (Jeukendrup, 2014). Another reported selecting CHO rich products in response to how he was feeling, which reflected an 'energy dip' at that point in time [Oliver 7 h 15 m]. Failure to explicitly relate the CHO content to the metabolic demands of running may imply that ultra-runners deemed this information to be so obvious, further explanation was not required.

The nutrient content of food items was a dominant component of individual ultra-runners food decisions, at key time points. In the early stages, some ultra-runners referred to the CHO content of foods and drinks to keep their 'energy topped up' and in the latter stages to manage 'energy dips'. Less emphasis was placed on the CHO content of foods and fluids when ultra-runners began to experience physical symptoms such as 'hunger' 'bloating' 'stomach cramps' and changes to their sensory preferences 'too sweet'. Providing evidence that physical symptoms experienced during the race and alterations to their sensory preferences took priority over their perceived need for specific nutrients.

5.4.3.2 Food Properties

The properties of the foods and drinks available were instrumental in the food choices of ultra-runners throughout the race. In the main this reflected the product's flavour, texture and portability, however, this was often considered against personal factors 'taste preferences' and physiological factors 'hunger'. Many ultra-runners appeared to categorise products from past experience based on these unique properties referring to them as 'sweet' 'sugary', 'savoury' 'salty', 'chewy' 'light' 'solid', 'dry' 'small and portable'. Categorising items in this way allowed ultra-runners to develop heuristic cues, which simplified the decision-making process, minimising the need for cognitive processing. This can be seen as some ultra-runners reported making a decision about the category of food they would select as they ran, with the actual food choice being decided at the aid station. Nicola [6 h 59] recalled 'I didn't have a, I'm going to have some pretzels, but it was I want something savoury this time, erm so there would be choice between what's savoury. But I kind of knew whether I wanted the salty or the sweet that time'.

The level of conscious thought when making these changes to their food choices appeared to vary between ultra-runners and time points. As an example, in the early stages of the race Eddie [5 h 11 m] anticipated a change from gels to solid foods based on 'what (he) knew about (himself)' in that 'solid foods seem to be handled a little bit better'. This past experience facilitated more automatic decisions as heuristic cues relating to the products structure simplified his food choice. In contrast, in the latter stages of the race he began to demonstrate an element of problem solving, as he perceived that his nutrition strategy was failing him. His decision to 'try something a little bit different' suggests a new experience that may require him to balance the cost and benefits of available products when altering his food choice.

Portability of products was key to a number of ultra-runners despite the short distance between aid stations (2.8 km compared to 16.0 to 22.4 km in past races) where they were able to consume food and drinks ad-libitum. Ivan [5 h 59 m] highlighted this stating 'I didn't actually eat anything straight away, I'd pick it up and then run and then consume it on the lap, when I felt I needed to eat it'. Similarly, Graham [5 h 40 m] favoured products he could 'space out through the run… Rather than taking them all in one go, I'd have one [shot]blok every mile, whereas with a gel it's kind of a one shot thing cos otherwise you end up with a pocket full of gunk'. In making this choice he explicitly considered the products consistency, while the structure and packaging was more of a latent consideration. Barry [4 h 59] who came 2nd overall in the race chose ‘things I could just tear the top off and get down me and move on quickly from each check point’, which indicates that portability and product packaging were important factors that were likely driven by performance. Eddie [5 h 11 m] echoed this with his plan to ‘stop at the aid station for as short a time as possible’.

5.4.4 Physiological Factors

The physiological factors that influenced the food choices of ultra-runners were associated with the prevention and management of physiological symptoms. Most pervasive of symptoms was GI discomfort, which represented any change in gut homeostasis across the length of the GI tract, from dryness of the mouth to urge to defecate. Other less common physiological symptoms included the presence or anticipation of dizziness, fatigue, cravings, hunger and muscle cramps. The level of influence placed on the prevention and management of symptoms for individual food choice was a reflection of their past and current experiences respectively. Current experiences often unique to the individual acted as key trigger points during the race, which required ultra-runner’s to consciously alter their food choices. As such, there was considerable inter-ultra-runner variability in this particular theme.

5.4.4.1 Prevention and Management of Gastrointestinal Symptoms

Gastrointestinal symptoms experienced in the past and during the current race were instrumental to the food choices of all ultra-runners. These included ‘bloating’ stomach ‘cramps’, nausea’ and the urge to defecate, although they were not always explicitly stated. Some ultra-runners referred to GIS as feeling ‘sickly’, yukky, ‘uncomfortable in (their) gut’ or ‘churny in (their) stomach’. One particular ultra-runner [Barry 4 h 59] reported making a detour to the toilet after lap 5, as a ‘safe guard’. He chose this course of action in response to ‘feeling a little bit grumbly’ in his gut, suggesting that he perceived this as an urge to defecate.

In the early stages of the race, many ultra-runners employed knowledge gained from past experience of consuming food and drinks during ultra-endurance training and competition in an attempt to prevent GIS. Choosing foods they knew they could tolerate, which included items trialed during the GT period of the preceding dietary intervention study. This provided evidence of an interaction with the personal factor ‘familiarity’. Despite preventative strategies, many ultra-runners experienced some level of GIS as the race progressed. As such, ultra-runners often altered their nutrition strategy, indicating that GIS’s acted as a pivotal trigger point within the food choice process. Oliver [7 h 15 m] specifically stated ‘I kind of felt a sickly feeling after them (gels), you know after about 4 hours of running. So I was like ok, at the next checkpoint I'll stay away from that’. Similarly, Eddie [5 h 11 m] stated ‘I made a conscious decision to deliberately walk through (the aid stations) without taking anything (solid) because my stomach was just feeling a little bit queasy’. Both extracts indicated that ultra-runners engaged in cognitive processing as they made changes to their food choices.

Altering their nutritional intake in this way was for some weighed against their experience of the demands of past races and the anticipated demands to complete the present race, although not explicitly stated. As such, some ultra-runners with intense symptoms resisted the urge to discontinue eating altogether, forcing themselves to consume something. Nicola [6 h 59 m] recalled ‘a couple of times later on, I would think I don't really want anything this time sort of thing, erm cos there was a couple of times when I forced a drink down'. Similarly, Ivan [5 h 45] and Max [6 h 31 m] recalled 'I was so bloated and had really bad cramps, I didn't feel like I wanted to eat anything, but I carried on because I knew I had to carry on eating' and 'You know you need to eat but you don't…your stomach doesn't feel like it wants it'. In almost all circumstances ultra-runners continued to ingest some form of nutrition, which indicates that the dominant factor in that situation was the metabolic demands of the race. In contrast to this, Harry [5 h 42 m] did not continue ingesting energy to override his urge to stop, instead he stated '(I) swilled it (energy drink) around my mouth and kept spitting it out', suggesting an alternative strategy was used to manage conflicting demands.

5.4.4.2 Prevention and Management of Physical (non-GI) Symptoms

The anticipation and/or presence of physical symptoms, excluding the GI tract also influenced the food choices of a number of ultra-runners. Symptoms were heterogeneous among ultra-runners, but largely appeared in the latter stages of the race. In particular, those who had a history of heavy sweating and/or muscle cramps attempted to manipulate their nutritional intake in an attempt to minimise dehydration and discomfort associated with cramping. This likely reflected a combination of existing nutrition knowledge and that gained from the dietary education session delivered in preparation for the diet intervention study (Chapter 4). During the dietary education session, ultra-runners were informed of the nutritional composition of fluids and their role in the prevention of dehydration and hyponatreamia.

Ultra-runners were also often aware of their susceptibility to other physical symptoms including 'dizziness', 'cravings', 'hunger' and fatigue 'energy dip' especially in the latter stages of the race. Two ultra-runners provided clear examples of this 'I predominantly go dizzy in marathons towards the end' [Chris 5 h 02 m] and 'usually on ultra's ….at about 18-19 miles (28.8-30.4 km), I sort of take a bit of a performance dip' [Jack 5 h 51 m]. Many ultra-runners attempted to mitigate the risk of these symptoms by 'eating constantly' consuming 'electrolytes and gels from the outset' 'topping up every hour'. This was facilitated by the availability of energy and CHO rich foods and drinks at the two aid stations along the 5.6 km loop. In contrast, some ultra-runners responded to their individual symptoms as they occurred, marking key trigger points that shifted the ultra-runner's food choices.

As ultra-runners developed symptoms, they employed unique strategies based on their assessment of their symptoms and their situation. Some strategies were based on their past experience while others were more experimental in nature, requiring conscious decision-making. Despite past experience of dizziness, Chris among others, recalled experimenting with his nutritional intake during the race 'I tried to think, what can solve this? I'd never tried the cake so I thought, I wonder if my body is just crying out for something random, so I had a little bit of that and luckily enough finished the lap and I didn't feel dizzy'. This description of his thought process indicates complex cognitive processes as he rules out familiar nutrition and considers alternative items as a potential solution. Furthermore, his current experience of resolving his physical symptom likely adds to his bank of knowledge, which may provide heuristic cues to simplify future food choices, for the management of symptoms in future races. Oliver [7 h 15 m] demonstrated the use of such cues from his past experience of what worked for him, actively assessing how he was feeling as he approached each aid station and making standardised food selections to address his perceived need. Solid foods where consumed to relieve 'hunger', whereas gels were the item of choice to 'keep (him) ticking over'.

5.4.5 Personal Factors

Personal factors that influenced the food choices of the ultra-runners referred to the values and to a lesser extent the beliefs they held. In general, the values included the individual's sensory preferences and the familiarity of food and drinks from past experience. Additionally, the availability and convenience of food and drink items in relation to the race was also important, although all ultra-runners reported a shift in their sensory preferences over the duration of the event. The beliefs referred to the healthful and ethical principles held by the ultra-runners, which were likely informed by their past experiences. While beliefs were strong influences for some individuals, they were less frequently discussed across the data corpus and therefore they have not been represented within this analysis.

5.4.5.1 Sensory Preferences

Sensory preferences referred mainly to the taste and texture of foods and fluids. Although informed by past experience, sensory preferences tended to evolve as the race progressed. This was illustrated by Eddie [5 h 11 m] as he recounted 'generally speaking I do like the more sweet things rather than savoury, however, I do find that the longer I go, savoury sort of seems to move up my food choice list'. He attempted to explain the trigger for this change stating 'I wouldn't put it down as a craving, more me body sort of saying to me look that ain't really what you need, this is sort of what you need'. His inability to explain fully the source of this seemingly innate desire, poses another dimension to the complexity of the food choice process.

Sensory preferences based on the texture of individual products also changed throughout the race for some ultra-runners. Solid 'real' foods, appeared to become more desirable as time progressed, which some related to physiological symptoms. Jack [5 h 51 m] explained 'I went more towards more whole foods towards the end of the race, the last sort of 4 laps [at ~34 km] or so'. This was to provide a 'bulk lining' in the stomach, which some implied helped to relieve symptoms such as 'hunger' or nausea. In contrast, Barry [4 h 56 m] stated 'I didn't bother [towards the end] with bananas or chips… I knew I would only have a certain period of time [before the end of the race] and I wanted something that would digest quicker than perhaps more solid food'. Indicating that his knowledge of the digestion and metabolism of food mediated his food choices in the latter stages of the race.

5.4.5.2 Convenience and Availability

The convenience of food items was often referred to in relation to the ease of consumption based on the product texture and portability. A number of ultra-runners reported that foods with 'dry' and 'chewy' properties were difficult to consume and subsequently avoided, particularly in the latter stages of the race. A preference for convenient items that were easy to 'chew' and 'swallow' illustrates the interaction between food properties and sensory preferences. Frank [5 h 33m] and Liam [6 h 04 m] expressed difficulty in consuming 'dry' 'chewy' foods, despite normally being able to tolerate all manner of foods including 'pork pie's and pastry'. The inability to consume similar consistency foods in this race likely reflected the physiological factor 'dehydration', rather than the properties of the food per sé.

Availability was a latent but pervasive factor that influenced ultra-runner's food choices, which only became apparent as ultra-runners recalled preferred foods they had selected or carried during past events. These included ‘rice pudding’, ‘milk’, ‘baby food pouches’, rice balls’, ‘nuts’, ‘sweet potato’, ‘wraps’ and ‘jam sandwiches that ultra-runners regarded as more nutritious than traditional sports nutrition products. Two ultra-runners captured the significance of the absence of preferred products during their interviews. Max [6 h 31 m] who noted ‘I didn’t have that much (to eat) because, there wasn’t a lot there that I normally have. Alan [4 h 29 m] more specifically recounted the profound effect on his state of mind and his subsequent performance of the absence of a specific item. He recalled planning to overtake a runner on his final lap ‘one of my mini goals during the race, was can I catch him?.... (I) caught up with him just at that (last) aid station and then when that (tasty orange) wasn't there, that was the thing that actually stopped me from pushing on to pass him’. Alan’s account demonstrated a deep level of conscious reflection, which he anticipated would influence future events ‘I think it’s a great lesson for other race, that actually it’s really important not to get too hung up on one thing’.

The availability and convenience of food choices was mediated by the research design of the race. Notably, the short distance between aid stations and the standardised portions increased the availability and convenience of food and drinks. Graham [5 h 40 m], among others used this opportunity to select CHO rich products that he regarded as ‘really easy to get down’ during the race, but that he would not normally consider. This was due to the higher weight to CHO ratio of the ‘isogel’ in comparison to ‘normal gels’. Indicating that this may not be feasible in self-sufficient ultra-endurance races that require athletes to carry all or part of their nutrition.

5.4.5.3 Familiarity

Familiarity was a pervasive value as ultra-runners commonly reported selecting products they had ‘tried before’ ‘used before’ or that had ‘worked before’, with rare exceptions. Jack [5 h 51 m], among others explicitly related the importance of selecting ‘familiar’ products to the prevention of GI distress stating ‘for me it’s familiarity (that influences my food choices), which is something I know I can eat, doesn’t give me an upset stomach’. This suggests that the value ‘familiarity’ was a mediator of the physiological factor ‘prevention of GIS.

The strength of this value appeared to vary considerably between ultra-runners and time points. This may have reflected the level of perceived risk associated with consuming unfamiliar products. Firstly, Max, [6 h 31 m], stated he ‘wasn’t flexible at all’ during the race, instead he emphasised that ‘during training is when you try new things out, because on a training run if you don’t like it and you end up being sick or something, that’s a training run…its fine!’ Secondly, while Ivan [5 h 45 m] mainly selected familiar foods he deviated from this approach at the start of the race, stating ‘it was the start of the race and I felt great and I thought, ooh a little bit of chocolate’. Suggesting that at that time he perceived his risk of GIS to be low. In contrast, Chris [5 h 02 m] deviated from his normal intake due to the presence of another physical symptom ‘dizziness’. Suggesting that familiarity and risk of GIS is balanced against the presentation of other physiological symptoms.

5.5 Discussion

It has been well established that ultra-runners consistently experience considerable energy deficits during competition (Clemente-Suarez, 2015; Stellingwerff, 2016), however, the reasons for such deficits have often been subject to speculation, likely due to the paucity of research. This study is the first to employ an in-depth qualitative approach to explore the factors that influence the food choices of ultra-runners. As such, the results of this study are unique and provide valuable insight into the complexity of the processes involved in making a series of individual food selections during an ultra-endurance race. Exploring the food choices of these athletes across numerous eating occasions adds to the existing theory, specifically the processes involved in making individual food selections (Bisogni et al., 2007; Connors et al., 2001; Furst et al., 1996; Sobal & Bisogni, 2009).

Unique to the current study was the evolving nature of both the influences and the personal food system within this specific ultra-endurance food choice environment. In brief, the factors that influenced the food choices changed over the course of the race, along with the level of cognitive processing as ultra-runners made their individual food selections. Smart and Bisogni (2001) reported a similar pattern with the influences and personal food system evolving across the athletic calendar. Their ice-hockey players placed greater importance on sport-specific influences during the competition season. Furthermore, they implemented rules and routines more rigorously at this time, suggesting greater emphasis was placed on these strategies within their personal food system when optimal athletic performance was required. Together these findings support existing theories that the food choice process is dynamic in nature (Furst et al., 1996).

5.5.1 Temporal Changes in the Factors that Influence Food Choice

Food choices in the early stage of the race were predominantly informed by their past experiences of prolonged running. Past experiences included knowledge about the food products they would typically consume during a long training run or competition, their normal physiological responses to ultra-running and their underpinning values. As the race progressed current experiences of the foods available and their physiological responses to the race became more prominent to their food choices. Their physiological responses to foods and the demands of the race acting as a trigger point, which changed their food choices. The influence of current experiences was also seen within some aspects of the personal factors, specifically sensory preference, convenience and familiarity. Ultra-runners reported changes towards plainer, savoury items and also selected foods with a suitable consistency to address their physiological state. Some foods became difficult to consume as they became more dehydrated, suggesting their convenience was impeded by their physiological response to the current race environment. The familiarity of individual foods was less influential to the athlete's food choices at key points during the race. This was evident when physiological factors presented a risk to their ability to complete the race. At times, individuals who experienced an energy dip or dizziness during the race tried unfamiliar foods in an attempt to alleviate these issues and enable them to continue. This suggests that ultra-runners actively considered their food choices in relation to immediate future events, specifically their goal for the race. Together with the past and current experiences this finding is consistent with the life course element of the food choice process (Devine, 2005; Furst et al., 1996; Wethington & Johnson-Askew, 2009).

Central to the life course perspective are two concepts, i) food choice trajectories and ii) transitions and turning points in food choice trajectories. Trajectories have been characterised as stable and persistent and reflect an accumulation of meaningful experiences through an individual's life (Devine, 2005). The ultra-runners generally focused their food choices on items that they were familiar with and those that met their anticipated physiological needs, suggesting stability within their food choices. Exceptions to this were limited in number and scope, for instance a single ultra-runner on one occasion reported selecting a food that he would not normally eat, prompted by what appeared to be hedonic hunger (Lowe & Butryn, 2007). The relative stability in food motives of the ultra-runners is therefore consistent with the trajectory concept. Previously it has been shown that changes to food choice within these trajectories can occur as a result of expected or unexpected transitions in their life (Wethington & Johnson-Askew, 2009). Although typically discussed in relation to the changing role of the individual, for example from child to adult or married to widower, transitions can also reflect changes to the food environment (Devine, 2005).

The ultra-runners demonstrated a combination of both expected and unexpected transitions in relation to the race nutrition environment. As a result of their past experiences of prolonged running, ultra-runners expected their taste preferences to change and for their physiological status to become compromised. They also anticipated that these changes would trigger them to alter their food choices, providing evidence of expected transitions. Similarly, Smart and Bisogni (2001) observed how expected transitions prompted college ice-hockey players to adjust their food choice. Their longitudinal study provided a detailed account of how transitions from high school to college and across the athletic calendar instigated changes in their eating behaviour. During the 'in season' period their nutritional intake was adjusted to avoid GI discomfort (i.e. avoiding foods that sat heavy in their stomach), which was a common feature for ultra-runners.

A minority of ultra-runners reported how their current experiences presented unfamiliar physiological symptoms that triggered them to change their food choices, representing unexpected transition points (Wethington & Johnson-Askew, 2009). This is likely due to the unique aspects of the race nutrition environment. Unlike transitions, where small adjustments to food choices are made to accommodate life experiences, turning points mark drastic changes to nutritional intake (e.g. adopting a vegetarian diet). This phenomena was not clearly present in the current study, however, negative experiences during the race provided meaningful experiences that ultra-runners expected to shape their future race nutrition.

5.5.2 Influential Factors that Shape Food Choices

The factors that influenced the food choices of ultra-runners were grouped into three themes that were confirmed via triangulation (i) food factors, (ii) physiological factors and (iii) personal factors. At present it is difficult to ascertain whether these factors have a comparable influence on the food choices of other ultra-runners or athletes competing in other sporting disciplines due to the limited extant research. In a recent review, Birkenhead and Slater (2015) indicated that the main factors likely to influence athletes included (i) physiological and biological factors, (ii) lifestyle, beliefs and knowledge, (iii) psychological, (iv) social and (v) economic. Within these factors there were a number of individual influences that were consistent with those reported by the ultra-runners and they will be discussed in turn.

The nutritional composition and unique proprieties of the foods and drinks available and how they compared to their usual race nutrition, was a pivotal factor that influenced the ultra-runners food choices. They focused primarily on the CHO, fluid and sodium content of the foods and drinks available during the race. Whereas football players in an earlier study were concerned more with the protein content of their diet (Long et al., 2011). The emphasis placed on different nutrients for these athletic groups, likely reflects their knowledge of the demands of the sport and their individual nutritional goals. Optimising fuel availability (Burke et al., 2011), minimising dehydration and avoiding EAH (Rehrer, 2001) are common goals for ultra-endurance athletes, due to associated risks for health and performance. In contrast, the footballers favoured protein foods to support them achieve their desired body composition goals (Long et al., 2011).

The food properties most pervasive to the food choices of the ultra-runners were flavour, texture and portability. These factors interacted with the personal and physiological factors. Typically, ultra-runners reported how they avoided unpalatable and dry foods that caused GIS or were difficult to consume while running. Furthermore, they chose portable foods as a convenient fuel source for when their energy levels were compromised even though food stations were very frequently available. The impact of flavour and texture was mediated by sensory preferences. This observation was also evident in ultra-runners during the Marathon Des Sables (Mccubbin et al., 2016). They described how sweet flavours became sickly and unpalatable and some illustrated how specific textures became difficult to consume. The portability of foods appeared to be a latent influence in relation to their nutrition plan, implied when a single ultra-runner discussed the weight efficiency of individual items.

The physiological factors consisted of the prevention and management of physical symptoms, the most pervasive being GIS. Consistently, studies have shown that the incidence of GIS amongst ultra-endurance athletes is high (Costa et al., 2016; De Oliveira, Burini, & Jeukendrup, 2014; Peters et al., 1999), although the influence on overall nutritional intake is less conclusive. Rehrer, Kemenade, Meester, Bronus &

Saris, (1992) noted a relationship between hypertonic fluids and fibre rich foods, which would suggest that athletes would be wise to avoid these foods during competition. Specific food avoidance prior to competition has been reported by college athletes who were concerned about GI discomfort (Smart & Bisogni, 2001). In contrast, an observational study that recorded the nutritional intake alongside the incidence of GIS reported conflicting findings. They found that GIS impeded the nutritional intake of multi-stage ultra-runners but not those competing in a single day event (Costa et al., 2016). Other influences within this theme that have been reported elsewhere include hunger (Birkenhead & Slater, 2015) and prevention of dehydration (Long et al., 2011). Some ultra-runners reported how their compromised energy levels acted as a stimulus to select CHO rich foods. One possible mechanism for this is that low glycogen stores induce compensatory behaviours that increase energy intake, however, evidence is presently equivocal (Hopkins, Jeukendrup, King, & Blundell, 2011).

Personal factors that influenced the ultra-runners food choices centered around a set of values, which were specific to the individual. These values shared some commonalities with other athletes. Firstly, the sensory preferences ‘taste’ and ‘texture’. Taste appears to be a considerable influence on the food choice of individuals from diverse population groups however, its contribution to the overall food choice appears to vary (Birkenhead & Slater, 2015). To illustrate this Smart and Bisogni (2001) documented how taste was the most dominant factor to influence the food choice of ice-hockey players during the off-season and least influential during the competition season.

The influence of the values availability and convenience was mediated by the research design of the preceding nutrition intervention study, which influenced the race structure. This was evident as ultra-runners commented on the short distance between aid stations compared to their typical ultra-endurance races. Secondly, the availability of products they would not normally have access to during self-sufficient races. Despite this availability and convenience have been discussed in the existing literature, albeit generally in relation to habitual nutritional intake (Birkenhead & Slater, 2015). The most pervasive value 'familiarity' has not been explicitly referred to in the literature reviewed. In this study, familiarity was often referred to in relation to the avoidance of GIS and there is considerable anecdotal evidence of this in ultra-endurance athletes. As such, familiarity may be inferred by ice-hockey player's accounts of how they ate a consistent diet before a competitive match and avoided foods likely to cause GI distress (Smart & Bisogni, 2001).

5.5.3 Personal Food System and Individual Food Choices

A consistent pattern between the current study and the existing food choices literature was the interconnectedness of individual factors (Bisogni et al., 2007; Connors et al., 2001; Smart & Bisogni, 2001). The current ultra-runners reported at times that they were presented with multiple conflicting or competing cues. This typically reflected physiological triggers, which resulted in transitions in their food choice trajectory. In the early stage of the race, food choices were predominantly based on their habitual race nutrition. As such, they were generally a result of unconscious decisions supported by heuristic cues that were formulated from previous experience. In the latter stages of the race, physiological triggers along with knowledge of the anticipated demands of the race required ultra-runners to engage in conscious decision-making when making food selections. This involved balancing multiple factors at an individual food choice occasion and problem solving in the event of unfamiliar physiological triggers. On rare occasions, problem solving was also required in familiar situations, indicating that heuristic cues had not yet been developed.

The cognitive and unconscious decisions-making process involved in the food choices of ultra-runners shared clear links with the personal food system within the food choice process model (Furst et al., 1996; Sobal & Bisogni, 2009). Firstly, the food choice values and the negotiations between them (Sobal & Bisogni, 2009) resemble the ultra-runners active decision-making process as they balanced multiple factors. Secondly, the classification of foods and the development of strategies to simplify recurring food decisions (Furst et al., 1996) are consistent with the unconscious food decisions that were facilitated by the ultra-runners use of heuristic cues.

To date, the only other athletic group known to have engaged in this two-component process was the group of ice-hockey players (Smart & Bisogni, 2001). They observed changes in the negotiation process across the athletic season, which indicated that the personal food system was situation specific. Unique to the current study was how the level of conscious decision making evolved over the course of the race, despite the consistent physical environment. Higher levels of cognitive processes were evident as ultra-runners were faced with physiological transitions. This suggests that the individual’s physiological status contributes to the complexity of the decision-making and changes in physiological stress as duration increases, alter food choices.

5.5.4 Strengths and Limitations

As a researcher engaged mainly in empirical quantitative research, a positivist model was employed to address the rigour of the study. Positivism in its basic sense refers to a theoretical framework that assumes independence of the world from observations of it (Braun and Clarke, 2013). Suggesting that by observing in a valid and reliable manner we can discover truth about the world. To distinguish from these traditionally quantitative terms, the current study provided evidence of this under the categories of credibility, transferability, dependability and confirmability as described by Lincoln and Guba (1985). In brief, evidence of credibility and dependability was provided via the use of existing food choice literature and explanatory and confirmatory probes to produce the interview schedule, the close timing of the interviews to the food choice occasions, the emersion of the researcher in the data corpus, while scrupulously following the six phases of thematic analysis (Braun and Clarke, 2006) and the subsequent scrutiny of the themes by the interviewer and thesis supervisors (Shenton, 2004). In addition, the triangulation process and the subsequent audit trail of the re-organisation of the original themes (Figure 5.1a) further enhanced the credibility and dependability of the final themes.

The main challenges to the transferability and confirmability of the study were addressed by the research as follows. Firstly, the ultra-runner's role as a research participant for the race and the preceding research tasks, including the empirical diet intervention and education, recording nutritional intake and GIS may have inadvertently altered their behaviour. The Hawthorne effect suggests that processes associated with a research intervention invariably make it difficult to isolate reality from the artificial situation (Onwuegbuzie & Leech, 2007), in this case the diet intervention from the factors influencing food choice during the race. Nevertheless, the ultra-runners experience as research participants are of interest to this study as they suggest that the nutrition information and the considerable nutrition support provided during the study were insufficient to overcome physiological challenges to optimal nutrition during the race. Therefore, the current findings indicate that further research is needed to identify nutritional strategies that address the physical factors, which dominated our ultra-runners food choices and limited their nutritional intake. To minimise the magnitude of Hawethorne affect the independence of the interviewer to the race and the earlier research project was emphasised to the interviewees, encouraging honest responses during the interview process (Shenton, 2004).

Secondly, factors that influence food choices are contextually sensitive (Furst et al., 1996) therefore the transferability of these findings to the wider population within the positivist model may be limited. Although, it could be argued that no two ultra-endurance races will be the same. Firstly, due to the potentially changeable environmental conditions, secondly, individual variances in physical fitness and finally, access to new nutrition information from social media and nutritional status before and during an ultra-endurance race. The detailed account of the research process, the ultra-runners' characteristics and the research design provides the reader with contextual information, to enhance the transferability of the current findings or to replicate the current study design (Krefting, 1991). Finally, the ultra-runners were recruited from around the UK (Scotland to South England) and the preceding nutritional intervention study had been lengthy and time intensive for participants, therefore to prevent further burden the occasional vague statement in the transcript went unconfirmed. In such circumstances, ambiguities in the data extract have been highlighted and the researcher has offered her interpretation from her experience as a Graduate Registered Sports Nutritionist and an avid distance runner. By acknowledging the researchers assumptions and beliefs the data analysis process has transparency and provides evidence of confirmability (Shenton, 2004).

5.6 Conclusion

This study adds to existing theories of the food choice process, specifically the evolving and dynamic nature of the decision-making process. There was a transition from subconscious, automatic decisions to cognitive decision-making processes when making food selections over the course of the race. Typically in response to changes in their physiological status and sensory preferences. Therefore ultra-runners and the practitioners supporting them should implement a nutritional plan that is responsive to these changes and simplifies the decision-making process, in an attempt to minimise the potentially detrimental impact on performance. The pervasiveness of the factor 'prevention and management of GIS' despite the preceding GT intervention indicates that further empirical research is needed to identify effective strategies to mininise the risk of symptoms. Furthermore, the sports nutrition industry and race organisers may have an integral role to play in developing and supplying a range of products that address the identified challenges to optimal nutritional intake. Specifically, the desire for different tastes and textures as the race progresses, without compromising the nutritional composition or the convenience of consuming nutrition on the move.

5.6.1 Practical Implications

- **Nutrition professionals supporting ultra-endurance athletes**:
    - Obtain a detailed account of the athletes past racing history including; GIS and other factors that influence food choice during training and

competition, to establish nutritional challenges and clearly defined nutritional priorities from the athlete's perspective

- Design a nutrition plan that not only addresses the athlete's history, but allows responsiveness to the changeability of the ultra-endurance race environment, especially when the environmental conditions can change considerably over the course of a race (i.e. 24 hr races that have marked temperature differences between day and night racing)
- Encourage athletes to try a variety of nutritional products, during a range of different training conditions (hot/cold temperature fast/slow pace easy/difficult technical terrain), to identify potential challenges associated with the anticipated race conditions.
- Encourage athletes to practice consuming products at the start and end of long training sessions, to establish the most agreeable strategy for the anticipated changes in the physiological status of the athlete during the race (i.e. hydration status, hunger/fullness).

- **Race organisers and sports nutrition product developers**
  - Develop/make available, a range of easy to consume products, in a variety of flavours (sweet and savoury), which miminise the risk of GIS (i.e. optimum osmolality) and consider the following:
    - Products that help to relieve hunger/prevent fullness
    - Products that are nutrient rich
    - Product transportability, in the context of the current climate of avoiding plastic waste
    - Availability of the nutritional composition and product packaging details.

Chapter 6 General Discussion and Conclusion

6.1 Introduction

Using a multi-method approach, the broad purpose of this thesis was to explore the reasons for the sub-optimal nutritional intake, typically observed during ultra-endurance competition. Furthermore, it sought to develop a nutritional strategy that would support athletes to meet the nutritional guidelines for ultra-endurance competition.

6.2 Synthesis of the Findings

Through a series of four studies, this thesis makes three main contributions to existing literature (illustrated in Figure 6.1) exploring the adequacy of ultra-endurance athletes' competition nutrition. Together, studies 1 and 2 (Contribution 1, Figure 6.1) indicate that nutritional knowledge was unlikely to be a mediating factor for sub-optimal nutritional intake. Instead, the avoidance of gastrointestinal symptoms was likely to be the most significant barrier to athletes implementing the CHO guidelines during competition (Section 2.3.2.2). Further analysis indicated that the food choices of ultra-endurance athletes was also strongly influenced by their understanding of the 'energy' demands of the sporting discipline and the 'nutritional' quality of the foods available. As described in Section 3.4, these factors are likely to act as conflicting drives and may in part explain the sub-optimal CHO intake.

There have been no previous studies exploring the level of nutritional knowledge in ultra-endurance athletes or the relationship with nutritional intake. It appears that the level of nutritional knowledge (36.0%) of other athletic populations (Jessri et al., 2010) may be inferior to these ultra-endurance athletes, however, direct comparison has not been possible due changes to the sport-specific questions in the nutrition questionnaire (ULTRA-Q). Nonetheless, nutrition knowledge is likely to be of greater importance to ultra-endurance athletes, compared to athletes competing in shorter endurance activities, partially due to the considerably larger energy demands. In addition, inappropriate nutritional intake during ultra-endurance activities has a greater risk of hypoglycaemia (Clemente-Suarez, 2015), dehydration, hyponatreima (Knechtle, 2013) and GIS (Stuempfle, et al., 2013), with considerable consequences for performance and health.

Interestingly, the level of nutrition knowledge of the ultra-endurance athletes (Study 1) was comparable to registered dietitians, but significantly lower than the SENr group who took part in this study. Therefore, ultra-endurance athletes would be advised to seek support from a member of the SENr, instead of a general dietitian. In contrast to the current findings, previous research has indicated that in both general population and athletic groups, higher levels of nutrition knowledge are associated with better nutritional practices, albeit to a modest extent (Spronk, 2014). This modest finding aligns with the current supposition that factors other than nutritional knowledge are more influential to an athlete's food choice during training and competition.

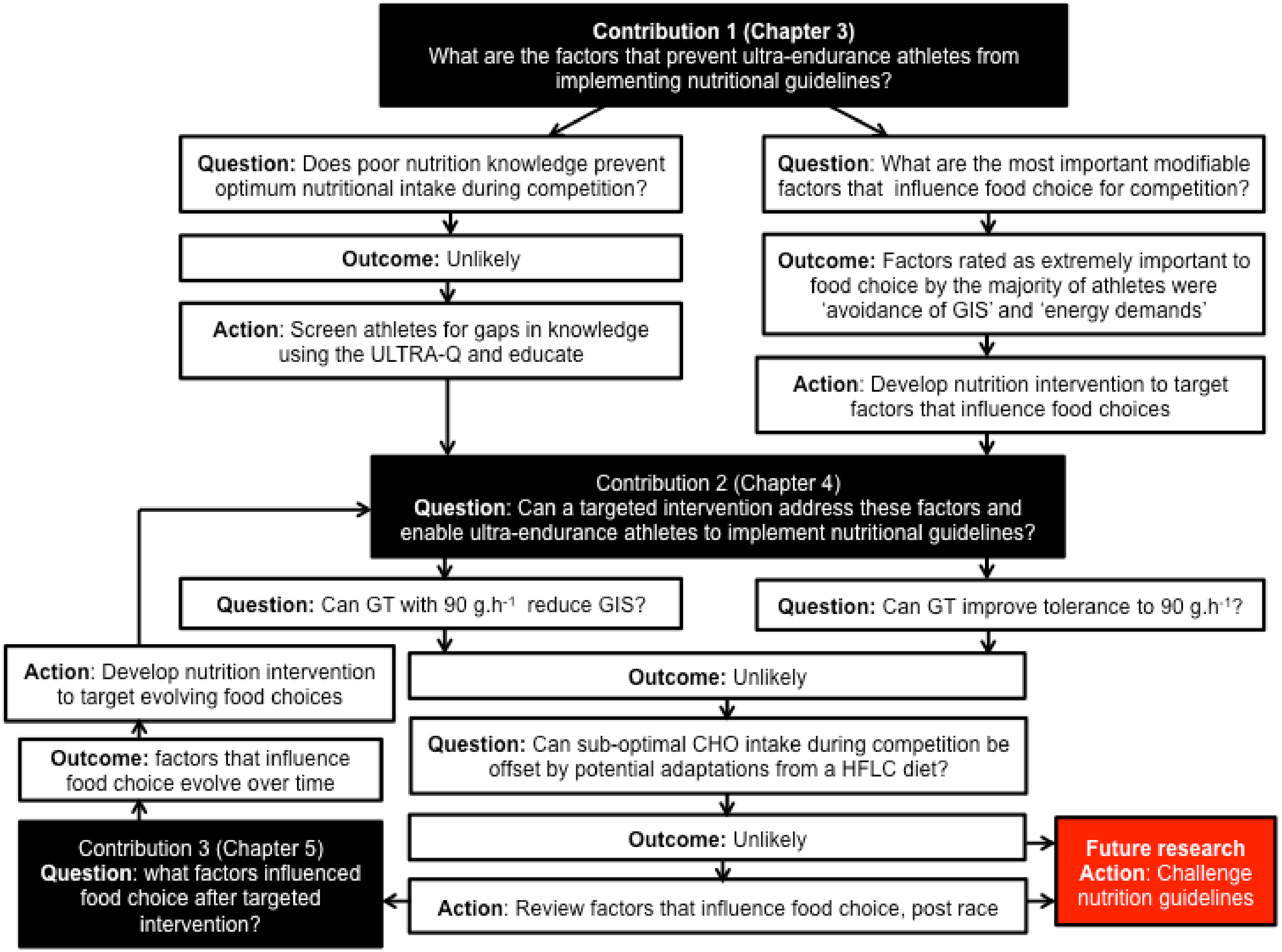


Figure 6.1. Schematic representation of thesis contribution to existing ultra-endurance literature and direction for future research

Unique to the current study was the importance placed on the 'nutritious' qualities of foods available. However, survey data has indicated that ultra-runners are almost twice as likely to follow a vegetarian or vegan diet (Turner-McGrievy, Moore & Barr-Anderson, 2016), suggesting they consume a diet containing nutrient rich foods. While there are a wide range of portable CHO rich foods, gels, drinks and confectionery products available for competitive use, they are mainly sweet flavoured and nutrient poor, which is likely to deter athletes from consuming adequate quantities of CHO. Furthermore, specific sports products and confectionary are not appropriate for those following a vegetarian/vegan diet, due to the gelatin content. Posing an additional challenge to nutrition professionals and the food industry in supporting athletes to better meet their nutritional requirements.

With a view to enhancing the nutritional intake and performance of ultra-endurance athletes, Study 3 (Contribution, Figure 6.1) employed a multicomponent nutrition intervention to target the main barriers (identified in Study 2) to achieving CHO recommendations. Although previous studies have combined multiple nutritional strategies in an attempt to optimise performance (Burke, et al., 2000 and Carey, et al., 2001), none to date have combined GT, specifically focused on increasing nutritional intake during competition, with strategies aimed at maximising fuel availability.

The initial phase of the intervention study sought to enhance the athlete's tolerance of higher rates of CHO during exercise and reduce the GIS associated with exercise. This consisted of a GT protocol that was based on the individual's typical nutritional intake and taste preferences. Although a previous GT study (consisting of a 3 hr run) has indicated that GI adaptations appear to be CHO specific (Costa, et al., 2017), it was predicted that taste fatigue, as observed by McCubin, et al., (2016) was likely to prevent the consumption of the same CHO rich product for the proposed 56 km ultra-endurance race, which was expected to last >4 hr. As such, during the GT period ultra-endurance athletes were permitted to select from a range of CHO rich products that were available during the race. These included fruit and malted fruit loaf for their higher nutrient density. Furthermore, to minimise the impact of the logistical challenges of consuming food and drinks on the move, these CHO rich products were made available at regular intervals in standardised portions, during the race.

The preliminary findings indicated that GT did not reduce the incidence or severity of GIS, however the median severity at baseline was relatively low, providing little scope for improvement. In contrast, two recent studies have reported reductions in GIS while consuming 90 $g.h^{-1}$ of CHO during a 3 hr laboratory protocol (Costa, et al., 2017; and Miall, et al., 2017). This was after 2 weeks of intensive GT. This disagreement may suggest that 1 hr GT was not sufficient to produce favourable changes for ultra-endurance distances. It is also possible that the difference between studies may be in part explained by the differences in the GT protocols. Although the GT intervention implemented by Costa, et al., (2017) and Miall, et al., (2017) was half the duration of the current intervention period, their runners ingested 90 g of CHOs for the first hour of all of their runs, whereas the ultra-runners ingested CHO for 50% of their runs progressing from 30 to 90 g over a four week period. This approach was employed to aid compliance as the ultra-runners were not accustomed to consuming CHOs during training. Furthermore, despite the effectiveness of the previous studies GT protocols for reducing GIS, athletes reported that their tolerance of the high CHO intake was low (Miall, et al., 2017).

A second observation of the effectiveness of this GT protocol, was that GT did not enable athletes to meet the CHO recommendations. In contrast, two of the top three athletes consumed CHO at rate of between 25 and 31 $g.h^{-1}$. This suggests that combining GT with other nutritional strategies considered optimal for performance may have negated any detrimental effect of sub-optimal CHO during competition. Together the pre-race meal and the CHO loading period likely resulted in muscle glycogen supercompensation, however this was not measured due to the logistical challenges of the study design. Despite this, muscle glycogen concentration is likely to have been considerably compromised, as muscle glycogen can reduce to detrimental levels after just 120 minutes, at comparable exercise intensities (Hawley, Schabort, Noakes, & Dennis, 1997). As such, low CHO intake during competition may have hindered performance in the latter stages of the race only.

If muscle glycogen was compromised and the actual CHO intake of these athletes (~55 $g.hr^{-1}$) was insufficient to maintain exercise intensity, athletes assigned to the HFLC diet (phase 2 of the multicomponent intervention) may have been expected to outperform those on the LFHC diet. This is assuming that the prescribed HFLC diet produced favourable adaptations (i.e. increased capacity for fat oxidation) that would translate into improved performance. In contrast, the findings indicated that the short-term HFLC diet (Study 3) did not produce a performance benefit. This finding was to some extent unsurprising given that several previous studies have failed to observe differences in performance, despite increased rates of fatty acid oxidation (Burke, et al., 2000 and Carey, et al., 2001). These earlier studies were shorter (3-5 hr) in duration than the current study (~5 hr 53 min), however, it remains likely that the level of CHO loading, coupled with the volume of CHO ingested during the 56 km race was sufficient to meet the fuel needs of the ultra-runners. To illustrate this point, theoretically the maximum CHO oxidation (1.7 $g.min^{-1}$, Jentjens & Jeukendrup, (2005)) for the average performance time (353 min and 354 min for the HFLC and LFHC diet groups, respectively) would require a total of ~600 g CHO during the race however, the average rate of CHO consumed (55.8 $g.h^{-1}$ and 55.9 $g.h^{-1}$, HFLC and LFHC respectively) by the ultra-runners equated to a total of ~328 g and the potential muscle glycogen stores of 350-700 g (Knuiman, et al., 2015) after CHO loading, suggest that CHO availability would range between 678 and 1028 g. As such, any potential beneficial effects of enhanced fat oxidation for performance may not have been detectable during this race distance.

Another plausible explanation for the absence of a performance difference was the variable diet compliance of the ultra-runners. In free-living individuals it is not possible to fully control dietary intake (without the expense of providing all food and drinks), as such the proportion of fat and CHO consumed by individual participants may have been insufficient to stimulate higher rates of fat oxidation. Therefore, blunting the potential to spare glycogen and improve performance. A final limitation of study 3 was the method used to assess differences in performance. It is impractical to use a repeated measures study design for ultra-endurance studies, furthermore performance differences can be difficult to detect over prolonged periods. Future studies exploring the impact of nutritional strategies on performance may benefit from recruiting a more homogeneous group of athletes and quantifying the coefficient of variance for the chosen performance measure. The latter will help to determine the minimum difference in performance required to detect a meaningful improvement.

Despite the limitations outlined above and the difficulties associated with interpreting the findings from a multicomponent intervention (Section 4.5), this study adds to existing literature relating to the optimum strategy for ultra-endurance competition. It suggests that when modest amounts of CHO (~55 $g.hr^{-1}$) are consumed during an ultra-endurance race (lasting ~6 hrs duration), after appropriate CHO loading, a HFLC does not confer any added benefit. This is likely because muscle glycogen and blood glucose concentrations were not sufficiently compromised. A benefit is more likely to be observed during events last >12 hr, especially when opportunities to refuel are limited during the race. Furthermore, failure to achieve the recommended CHO intake, despite GT and the vast availability of CHO rich products during the race, raises two important questions. Firstly, what factors influenced the food choice of the ultra-runners that took part in the targeted nutrition intervention. Reviewing the food choices at this point (using a qualitative approach) provided an ideal opportunity to gain a greater understanding of the challenges athletes face in meeting the demands of competition, and could be used to refine future targeted nutritional interventions (Chapter 5). The second, and possibly more interesting point refers to the appropriateness of current CHO recommendations. Posing the question 'Is 90 $g.hr^{-1}$ superior to 60 $g.hr^{-1}$, for ultra-endurance performance, when muscle glycogen concentration is optimised prior to competition. The latter is a recommendation for future research (Figure 6.1).

The final contribution from this thesis (Figure 6.1) is the increased understanding of the food choice process. Specifically, the changes that occur in relation to the factors that influence an ultra-endurance athlete's food choices, and the complexity of the decision making process, as a race evolves. The main finding of this qualitative study confirmed the earlier observation (Chapter 3), that several factors were instrumental to the food choices of ultra-endurance athletes during competition and they often acted as conflicting drivers. The dominant factors drawn from the thematic analysis fell into the three broad categories of food factors, physiological factors, and personal factors. These categories included many of the individual factors rated as important by the majority of ultra-endurance athletes in the earlier questionnaire study (Chapter 3). This included the prevention of GIS, taste, sometimes referred to as flavour or in relation to taste preferences, and the portability and convenience of food items, which appeared to reflect the factor 'easy to consume during training and competition'. The latter factor was surprising given the high availability of a variety of foods and fluids.

Less pervasive during the analysis of the interviews was the importance of the 'nutritious' qualities of foods and drinks, this was despite this being rated as important by the majority of ultra-endurance athletes in the aforementioned questionnaire (Study 2). Another distinction between these two studies was the dynamic nature of the factors influencing their food choices, which became apparent during the interview process. As such, the final research study indicated that the multiple factors that often present as conflicting influences evolved over time. Furthermore, the level of active decision-making when making their individual food choices changed as the race progressed, with more conscious decision-making processes at key time points. This may impede the speed of individual food choices and have a negative impact on performance as individual deliberate at the aid stations.

While the initial studies contained in this thesis provided insight into the main factors influencing food choice for ultra-endurance training and competition, this is the first study to explore the complexity of the food choice process of ultra-endurance athletes in a competitive environment. There is an abundance of research in the literature exploring the complexity of food choice, but this has predominantly been limited to general population studies (Bisogni et al., 2007; Connors et al., 2001; Furst et al., 1996; Sobal & Bisogni, 2009). While some of the factors influencing the food choices of these population groups are wildly different to those reported by ultra-endurance athletes, there are a number of commonalities between the current findings and the existing theory underpinning the food choice process. Current observations of the temporal influence on the factors influencing the food choices during the race were akin to the life course perspective (Devine, 2005), as the past and current experiences of the ultra-runners influenced the athletes food decisions at specific times during the race. Similarly, the negotiations between several factors that acted as conflicting drivers for food choice were consistent with the personal food system, which was a key component of the theory underpinning the food choice process (Sobal & Bisogni, 2009).

A unique finding in the current study was how the level of conscious decision-making evolved over time. Previous studies have noted that individuals build heuristic cues for routine food choices that simplify the food choice decision (Furst, et al., 1996 and Smart & Bisogni, 2001). This was evident within the current ultra-runners, however, at key times a number of individuals reported deviating from their normal routine, which required a more conscious decision-making process. In the main this was stimulated by their current experiences of taste fatigue and physiological symptoms such as hunger or GIS, indicating that food choices and the food choice process was situation specific. Athletes and the individuals or teams supporting them may use knowledge of this process as a framework to build nutritional strategies that facilitate speedy food choices. This could be achieved by introducing race nutrition practices into their training schedule to identify their individual tolerance to CHOs and to trial a variety of approaches to overcome the potential challenges of achieving adequate fuel that is acceptable during competition.

6.3 Future Research Directions

Together the findings of the exploratory studies (Chapter 3 and 5) provided a detailed insight into the challenges in meeting the current CHO guidelines, faced by ultra-endurance athletes competing in single day events. Despite this, the targeted nutritional intervention in Chapter 4 failed to enable ultra-endurance athletes to ingest CHO at the recommended rate, casting doubt on the acceptability and tolerability of said guidelines. Furthermore, it is unclear whether higher rates (90 $g.hr^{-1}$) of CHO intake are superior to moderate intakes (60 $g.hr^{-1}$) for single day events lasting ~6hrs, or whether short-term HFLC diets provide additional benefits, when CHO intake is compromised.

Given the considerable variability in the duration of ultra-endurance competition and the uniqueness of the environmental and logistical challenges of each event, there are many unanswered questions within this sporting domain. Firstly, in relation to the challenges to optimal nutritional intake during competition, future studies should seek to explore the subtle differences between the factors influencing the food choices of ultra-endurance athletes taking part in different events. Exploring the food choice experiences of ultra-endurance athletes during single day events in other modes of activity (i.e. cycling, triathlon and adventure racing) and those competing in multi-day stage events and semi-continuous events, within a range of environmental conditions. Furthermore, they should explore the cognitive processes involved in the selection of foods during training and competition to further expand current understanding of the complex negotiations between the multiple factors influencing food choices during competition. It is anticipated that this would provide evidence that will enable nutrition practitioners to better support these athletes to optimise their nutritional intake and ultimately their performance.

Secondly, despite the absence of a statistically significant benefit in GIS after GT and the failure to meet the recommended CHO intake during the 56 km, there appears to be an improvement for individual ultra-runners. The variability in the ad-libitum CHO intake of these ultra-runners, despite GT could reflect individual variability in tolerance to CHO intake. In contrast, the final study suggests the lower CHO intake may be in part due to factors other than GIS, such as taste fatigue and hunger, with ultra-runners favouring savoury and solid foods with a lower CHO density at these times. As such, a more individualised approach to nutritional intake during ultra-endurance competition may be warranted. Therefore, future studies aimed at improving gut symptoms and CHO intake in ultra-endurance athletes need to incorporate strategies to overcome these additional challenges, especially for athletes at greatest risk of GIS and consequently impaired nutritional intake. As an example, GT studies should target athletes with a history of GIS, competing in longer duration events and should incorporate both sweet and savoury CHOs to prevent taste fatigue and some CHO rich solid foods to address feelings of hunger.

Thirdly, although a meaningful difference in performance between ultra-endurance runners allocated to the HFLC and LFHC diet interventions was not detected, more research is needed to further evaluate the efficacy of these diets. Early evidence has suggested that fat oxidation rates can be increased by adherence to a short term HFLC (Cameron-Smith et al., 2003), however this has not yet translated to statistically significant improvements in ultra-endurance performance. Despite this, a trend for enhanced performance has been observed for rowers (12 hrs, Robins, et al., 2005) and the latter stages of a 5 hr cycle (Carey, et al, 2001), suggesting that benefits may be expected when muscle glycogen concentrations are more likely to be compromised. Therefore, particular attention should be placed on prolonged ultra-endurance events (lasting >12 hr) or shorter ultra-endurance events when the logistical challenges of carrying sufficient CHO are likely to impair exogenous CHO availability.

Finally, to date, the current CHO recommendations for during competition appear to be based on a combination of expert opinion and maximum oxidation rates, in the fasted state. They do not appear to consider the logistical challenges associated with ultra-endurance competion or the athletes tolerance to such high volumes of CHO. Furthermore, there is an absence of empiracle research to support the added performance benefit of these CHO guidelines. As such, future studies would benefit from quantifying the potential benefit of ingesting 90 $g.hr^{-1}$ compared to 60 $g.hr^{-1}$, during a simulated ultra-endurance laboratory protocol.

6.4 Conclusion

In conclusion, the primary findings from the intervention study demonstrate that there were no differences in performance or exercise induced GIS after implementation of a multicomponent dietary intervention. Furthermore, despite systematic efforts to address the main challenges to optimum nutritional intake during ultra-endurance competition, ultra-runners were unable to meet the current recommended CHO guidelines during a 56 km race. The significance of these findings for overall ultra-endurance performance trends are unclear, however, it is clear from the final study that the factors that influence the food intake of ultra-runners are complex and dynamic. Similarly, the level of cognitive processing involved in making individual food selections during race conditions are variable. Ultra-endurance nutrition research is currently in its infancy and therefore requires further exploration to fully support athletes to overcome the multifaceted challenges and barriers to optimal nutritional intake. In the absence of robust nutritional intervention studies that demonstrate a benefit to performance, nutritional intake or GIS, precise guidance cannot be made at this time.

Instead, the key take home messages from this thesis are as follows:

- Athletes: Ultra-endurance athletes should seek nutritional support from a registered sports and exercise nutritionist, with specific knowledge and experience of the demands of ultra-endurance competition.
- Athletes: Although GT, did not reduce GIS or enable athletes to meet the CHO guidelines, it is wise for ultra-endurance athletes to trial new products during training to identify the most effective strategy for their intended race. Furthermore, they should trial a broad spectrum of products, with different properties. This will support athletes to determine the most appropriate product to address a range of anticipated scenarios i.e. products that relieve hunger and those that are tolerated when GIS are present.
- Nutrition professionals and industry: In addition to the demands of the race, registered sports and exercise nutritionists, race organisers and product developers need to consider ultra-endurance athletes nutritional preferences when making recommendations or providing/developing nutritional products for competition. Given the results of this thesis and the current climate, this is likely to include the avoidance of GIS, the desire for nutritious foods, and products that are ethically sourced and packaged.

- Researchers: Research priorities include (i) comparison of high (90 $g.hr^{-1}$) and moderate (60 $g.hr^{-1}$) CHO intake for ultra-endurance performance, in events of different durations (ii) comparison of HFLC and LFHC diets during prolonged ultra-endurance events (iii) identify the optimum GT protocol for reducing GIS for ultra-endurance athletes with a past history of severe symptoms.

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Appendices

Appendix 1 Sports Nutrition Knowledge Questionnaire (ULTRA-Q)

Below are 20 questions assessing a variety of sports nutrition topics, please answer them as best you can.

Nutrients

1. Which of these foods are <u>high</u> in *carbohydrate*? (Tick one box per food).

	Yes	No	Unsure
Chicken breast	☐	☐	☐
Baked beans	☐	☐	☐
White bread	☐	☐	☐
Butter	☐	☐	☐
Cornflakes	☐	☐	☐
Rice pudding	☐	☐	☐

2. Which of these foods are <u>low</u>, <u>medium</u> and <u>high</u> in *protein*? (Tick one box per food).

	Low	Medium	High	Unsure
Chicken breast	☐	☐	☐	☐
Baked beans	☐	☐	☐	☐
Apple	☐	☐	☐	☐
Margarine	☐	☐	☐	☐
Cornflakes cereal	☐	☐	☐	☐
Peanuts	☐	☐	☐	☐

3. Do you think these foods are <u>high</u> or <u>low</u> in *fat*? (Tick one box per food).

	High	Low	Unsure
Avocado	☐	☐	☐
Baked beans	☐	☐	☐
Pasta	☐	☐	☐
Margarine	☐	☐	☐
Cottage Cheese	☐	☐	☐
Rice pudding	☐	☐	☐
Peanuts	☐	☐	☐
White bread	☐	☐	☐
Honey	☐	☐	☐
Hard cheese (e.g. Cheddar)	☐	☐	☐

4. Which of these foods are <u>higher</u> or <u>lower</u> in *saturated fat* compared to *unsaturated fat*? (Tick one box per food).

	Higher in saturated fat	Lower in saturated fat	Unsure
Butter	☐	☐	☐
Canola margarine	☐	☐	☐
Whole milk	☐	☐	☐
Red meat	☐	☐	☐
Salmon	☐	☐	☐
Chocolate	☐	☐	☐
Peanuts	☐	☐	☐

5. Would you <u>agree</u> or <u>disagree</u> with the following statements? (Tick one box per statement).

	Agree	Disagree	Unsure
a. A high carbohydrate diet helps to reduce muscle breakdown in the body.	☐	☐	☐

b. Tannins in tea decrease the amount of iron absorbed from food. ☐ ☐ ☐
c. Spinach is a good source of iron that is easily absorbed by the body. ☐ ☐ ☐
d. Ascorbic acid (Vitamin C) increases the amount of iron absorbed from food. ☐ ☐ ☐

6. Would you <u>agree</u> or <u>disagree</u> with the following statements? (Tick one box per statement).

	Agree	Disagree	Unsure
a. Whole milk contains more protein than skimmed milk.	☐	☐	☐
b. Whole milk contains more calcium than skimmed milk.	☐	☐	☐
c. Green leafy vegetables contain calcium that is easily absorbed by the body.	☐	☐	☐
d. Thick cut chips are a lower fat choice than thin cut chips	☐	☐	☐

Fluid

7.The optimum amount of *fluid* needed during a <u>two-hour intense training session</u> is: (Tick one box only.)

1 X 750ml water bottle ☐ 3 X 750ml water bottles ☐
Athletes should create an individualised fluid plan based on sweat rate ☐
Unsure ☐

8. In an <u>ultra-endurance</u> race, what is the recommended amount of *sodium* per litre of fluid? (Tick one box)

0 g (it is not needed) ☐ 1-1.7 g per litre ☐
1.7-2.9 g per litre ☐ 3-3.5 g per litre ☐
Unsure ☐

9. For optimum <u>hydration</u>, the percentage of *carbohydrate* in a 'sports drink' should be: (Tick one box only).

5-10% ☐ 10-15% ☐
20-25% ☐ Unsure ☐

10. Would you <u>agree</u> or <u>disagree</u> with the following statements? (Click on one box per statement).

	Agree	Disagree	Unsure
a. Fluid loss of only 2% of an athletes body weight can reduce endurance performance especially in the heat	☐	☐	☐
b. Weighing athletes before and after a training session would be a good way to determine each individual's fluid requirements.	☐	☐	☐
c. Fruit juice is a good fluid to have during a training session	☐	☐	☐
d. Energy drinks such as 'Red Bull' are good drinks to have 30 minutes leading up to exercise.	☐	☐	☐
e. For rapid recovery between training sessions an athlete should consume 1.5 litres of fluid for every kilogram of body weight lost	☐	☐	☐

Recovery

11. To <u>replace energy stores</u>, the most important *nutrient* to replace after a one-hour run is: (Tick one box only).

Carbohydrate ☐ Protein ☐
Fat ☐ Unsure ☐

12. Which one of the following set of 2 snacks would you suggest that an athlete eat after <u>endurance training</u>? (Tick one box for each question a-d).

a. 2 slices white bread, 2 tsp peanut butter ☐ 1 portion of chips ☐ Unsure ☐
b. 1 flapjack ☐ 2 sausage rolls ☐ Unsure ☐
c. 150g pot of yoghurt ☐ 2 apples ☐ Unsure ☐

d. 2 low fat meat pies	☐	190 g pot of rice pudding	☐	Unsure	☐

13. Which one of the following set of 2 snacks would be most effective at replacing carbohydrate stores (Tick one box for each question a-d).

a. 340 ml can of Coke	☐	3 cups of green salad	☐	Unsure	☐
b. 1⁄2 cup chopped dried dates	☐	1 meat pie	☐	Unsure	☐
c. 180 g skinless chicken breast	☐	2 slices white bread, 2 tsp marmite	☐	Unsure	☐
d. 100 g bag of marshmallows	☐	100 g bag of peanut M and M's	☐	Unsure	☐

14.When an athlete is training daily, the optimal time to eat after exercise is: (Tick one box only).

Between 2-3 hours	☐	Within one hour	☐
Within 45 minutes	☐	Within 30 minutes	☐
Unsure	☐		

15. Which of these statements is the most accurate definition of the term 'Glycaemic index'. (Tick one box only.)

The amount of carbohydrate a food contains	☐
The extent to which carbohydrate food raises blood sugar levels	☐
The extent to which protein food raises blood sugar levels	☐
The extent to which carbohydrate food raises blood pressure	☐
Unsure	☐

Body comp

16. True or false, if exercise is unchanged, it is possible for an athlete to put on weight if they have six glasses of fruit juice in addition to their normal food intake (Tick one box only).

True ☐ False ☐ Unsure ☐

17 If an athlete was trying to lose weight and they had the following snacks to choose from, which one should they choose from each line? (Tick one box for each question a-f).

a. 4 salami sticks	☐	1 piece fruit	☐	Unsure ☐
b. 2 packets of crisps	☐	1 cereal bar	☐	Unsure ☐
c. 1 pot of rice pudding	☐	1 large chocolate bar	☐	Unsure ☐
d. 100g peanuts	☐	1 glass of chocolate milk	☐	Unsure ☐
e. 1 pot of yoghurt	☐	1 croissant with salad	☐	Unsure ☐
f. 6 crackers with cottage cheese	☐	6 crackers with cheddar cheese	☐	Unsure ☐

18. Do you agree or disagree with the following statements? (Tick one box per statement).
If an athlete wanted to lose weight, they should:

	Agree	Disagree	Unsure
a. Exchange 1 tsp of butter on sandwiches for 1 tsp of regular margarine.	☐	☐	☐
b. Eat more Cheddar cheese than Edam cheese.	☐	☐	☐
c. Eat less salami and more turkey breast.	☐	☐	☐
d. Stop eating pasta and rice after 4pm.	☐	☐	☐
e. Exchange yoghurt, muesli bar and fruit snacks for protein shakes.	☐	☐	☐

Supplements

19. Which of the following statements are true? (Tick one box per statement).

	Agree	Disagree	Unsure
a. Vitamin C should be routinely supplemented by athletes	☐	☐	☐
b. Iron tablets should be taken when an athlete feels extremely tired and is pale.	☐	☐	☐
c. Multivitamin tablets should be taken by most athletes.	☐	☐	☐

d. B vitamins should be taken when feeling low in energy.	☐	☐	☐
e. Salt tablets should be used for athletes that get cramp during exercise.	☐	☐	☐
f. Appetite suppressants are recommended for athletes with a weight loss goal.	☐	☐	☐

20. Do you agree or disagree with the following statements? (Tick one box per statement)

	Agree	Disagree	Unsure
a. Sports bars can be contaminated with substances that are on the banned list from the World Anti Doping Association	☐	☐	☐
b. Caffeine can improve endurance performance by reducing the perception of effort	☐	☐	☐

Thank-you for your time, it is very much appreciated.

Appendix 2 Food Choices Questionnaire (ULTRA-FCQ)

Please rate how important each of the factors are to you when making food choices for training and competition

Factors that influence food choice	Extremely unimportant	Unimportant	Slightly unimportant	Neither important nor unimportant	Slightly important	Important	Extremely important
1. Takes no time to prepare	☐	☐	☐	☐	☐	☐	☐
2. Can be cooked quickly	☐	☐	☐	☐	☐	☐	☐
3. Is not expensive	☐	☐	☐	☐	☐	☐	☐
4. Is good value for money	☐	☐	☐	☐	☐	☐	☐
5. Can be bought in shops close to where I live or work	☐	☐	☐	☐	☐	☐	☐
6. Is easy to prepare (e.g. cooked in one pan, does not require defrosting)	☐	☐	☐	☐	☐	☐	☐
7. Can be cooked very simply	☐	☐	☐	☐	☐	☐	☐
8. Keep me awake/alert	☐	☐	☐	☐	☐	☐	☐
9. Makes me feel good	☐	☐	☐	☐	☐	☐	☐
10. Tastes good	☐	☐	☐	☐	☐	☐	☐
11. Smells nice	☐	☐	☐	☐	☐	☐	☐
12. Has a pleasant texture	☐	☐	☐	☐	☐	☐	☐
13. Contains a lot of vitamins and minerals	☐	☐	☐	☐	☐	☐	☐
14. Is high in protein	☐	☐	☐	☐	☐	☐	☐
15. Is high in carbohydrate	☐	☐	☐	☐	☐	☐	☐
16. Is high in fibre and roughage	☐	☐	☐	☐	☐	☐	☐
17. Are made from natural ingredients (no artificial additives or preservatives)	☐	☐	☐	☐	☐	☐	☐
18. Keeps me healthy	☐	☐	☐	☐	☐	☐	☐
19. Is nutritious	☐	☐	☐	☐	☐	☐	☐
20. Is good for my skin, teeth, hair and nails	☐	☐	☐	☐	☐	☐	☐

Factors that influence food choice	Extremely unimportant	Unimportant	Slightly unimportant	Neither important nor unimportant	Slightly important	Important	Extremely important
21. Help prevent illness (upper respiratory infections, high cholesterol)	☐	☐	☐	☐	☐	☐	☐
22. Improve immune function	☐	☐	☐	☐	☐	☐	☐
23. Give variety to my diet	☐	☐	☐	☐	☐	☐	☐
24. Helps me maintain a healthy weight	☐	☐	☐	☐	☐	☐	☐
25. Helps me keep low body fat percentage	☐	☐	☐	☐	☐	☐	☐
26. Helps maintain muscle power	☐	☐	☐	☐	☐	☐	☐
27. Are brands I trust	☐	☐	☐	☐	☐	☐	☐
28. Are good quality products	☐	☐	☐	☐	☐	☐	☐
29. Are easy to digest before training and competition	☐	☐	☐	☐	☐	☐	☐
30. Does not cause discomfort (stomach ache, loose stools, wind, bloating)	☐	☐	☐	☐	☐	☐	☐
31. Is what I usually eat	☐	☐	☐	☐	☐	☐	☐
32. Does not compromise ability to train/compete	☐	☐	☐	☐	☐	☐	☐
33. Give me energy	☐	☐	☐	☐	☐	☐	☐
34. Helps recovery between training and competition sessions (e.g. 2 sessions per day)	☐	☐	☐	☐	☐	☐	☐
35. Help me cope with high training and competition demands	☐	☐	☐	☐	☐	☐	☐
36. Can improve performance	☐	☐	☐	☐	☐	☐	☐
37. Can be carried easily while training and competing	☐	☐	☐	☐	☐	☐	☐
38. Can be consumed easily while training	☐	☐	☐	☐	☐	☐	☐

and competing (i.e. performing at high intensity)							
39. Are part of my normal competition routine	☐	☐	☐	☐	☐	☐	☐