Effects of intermittent fasting in the form of 16:8 time-restricted eating on nutrient intakes, body composition and indices of running performance in endurance athletes

Henry Michael Langton, MSc.

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Henry Michael Langton | Bachelor of Science

Thesis submitted for the award of Master of Science (MSc)

School of Health and Human Performance

Dublin City University

Supervisor

Dr Brendan Egan

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i. Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Masters of Science is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Mr Henry Michael Langton

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Candidate no: 99824485

Date: 12th January 2022

ii. Acknowledgements

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vi. *List of abbreviations*

One repetition maximum	1RM
American College of Sport Medicine	ACSM
Alternate-day fasting	ADF
Analysis of covariance	ANCOVA
Analysis of variance	ANOVA
Adenosine triphosphate	ATP
Branched-chain amino acids	BCAAs
Body fat percentage	BF%
Bioelectrical impedance analysis	BIA
Body mass	BM
Body mass index	BMI
Control diet	CD
Continuous energy restriction	CER
Carbohydrate	CHO
Control	CON
Energy availability	EA
Essential amino acids	EAAs
Energy expenditure of exercise	EEE
Energy intake	EI
enzyme-linked immunosorbent assay	ELISA
Every other day diet	EODD
Every other day fasting	EODF
Fixed blood lactate concentration	FBLC
Fat-free mass	FFM
Fat mass	FM
β-Hydroxy β-Methylbutyrate	HMB
Homeostatic model assessment of insulin resistance	HOMA-IR
Heart rate	HR
International Association of Athletics Federations	IAAF
Intermittent energy restriction	IER

Intermittent fasting	IFast
Insulin-like growth factor 1	IGF-1
Intention to treat	ITT
Lean body mass	LBM
Normal diet	ND
Non-significant	NS
Per protocol	PP
Running economy	RE
Relative energy deficiency in sport	RED-S
Resting energy expenditure	REE
Respiratory exchange ratio	RER
Rate of force development	RFD
Rate of perceived exertion	RPE
Resistance trained	RT
Standard deviation	SD
Total daily energy expenditure	TDEE
Thermic effect of food	TEF
Time-restricted eating	TRE
Time-restricted feeding	TRF
Carbon dioxide production	VCO_2
Oxygen uptake	$\dot{V}O_2$

Units of measurement

bpm	Beats per minute	km	Kilometre
g	Gramme	km/h	Kilometre per hour
h	Hour	m	Metre
kcal	*Kilocalorie*	min	Minute
kcal/g	Calories per gram	ml	Millilitre
%/kcal	Percentage calories	mM	Millimolar
kg	Kilogram	VO_{2peak}	Maximal oxygen consumption
kJ	Kilojoule	y	Year

vii. Abstract

Henry Michael Langton

Effects of intermittent fasting in the form of 16:8 time-restricted eating on nutrient intakes, body composition and indices of running performance in endurance athletes

Eight weeks of time-restricted eating (TRE) in concert with habitual exercise training was investigated for effects on body composition, energy and macronutrient intakes, indices of endurance running performance, and markers of metabolic health in endurance athletes.

Male middle and long-distance runners (n=23) were randomly assigned to TRE (n=12), or habitual dietary intake (CON; n=11). TRE required participants to consume all of their dietary intake within an 8 h eating window (so-called "16:8" TRE), but dietary patterns, food choices, and energy intake were *ad libitum* during this window. Participants continued their habitual training during the intervention period. Participants completed an incremental exercise test before (PRE) and after (POST) the 8-week intervention for assessment of blood lactate concentrations, running economy and maximal oxygen uptake. Fasted blood samples were analysed for glucose, insulin, and triglyceride concentrations. Dietary intake was assessed at PRE, MID (week 4), and POST using a four-day semi-weighed food diary.

Seventeen participants (TRE, n=10; CON, n=7) completed the intervention. Training load did not differ between groups for the duration of the intervention period. TRE resulted in a reduction in body mass (mean difference of -1.92 (95% CI, -3.52 to -0.32) kg, P=0.022, η^2_p=0.321). Self-reported daily energy intake was lower in TRE at MID and POST (group*time interaction, P=0.049). No effect of TRE was observed for oxygen consumption, respiratory exchange ratio, running economy, blood lactate concentrations or heart rate during exercise, nor were any effects on glucose, insulin or triglyceride concentrations observed.

Eight weeks of 16:8 TRE in middle and long-distance runners resulted in a decrease in body mass commensurate with a reduction in daily energy intake but did not alter indices of endurance running performance or metabolic health.

KEYWORDS: body composition; intermittent fasting; lactate threshold; nutrition periodisation; running; training load.

1 Chapter One: Introduction

Periodic exposure to fasting has endured throughout human development primarily out of necessity for survival but also as a learned progression to ration when food deficits were determined by circumstantial stresses. Hunter-gatherers would have had to learn the skills of rationing as there would have been a high energy cost absorbed during hunting and a scarcity of other food sources due to seasonal variations. On the other hand, deliberate Intermittent Fasting (IFast) and its considered health benefits may have been widespread in ancient civilization, and our best interpretations on this practice is quite recent in terms of human existence with it being dated back to the last two Millennia (Carlson and Hoelzel, 1946; Patterson *et al.*, 2015). The best known IFast behaviours in humans are assimilated in religious teachings with most obvious examples being in Islam, fasting from sunrise to sunset during Ramadhan (Maughan, Fallah and Coyle, 2010; Levy and Chu, 2019), abstinence and fasting during lent in Christian culture, and Yom Kippur and Tisha B'Av fasting in Judaism.

Recently there has been a renewed interest in IFast by sports scientists and fitness enthusiasts owing to the importance of exercise nutrition in optimizing athletic performance. The plurality of studies initially investigating performance and fasting observed athletes during Ramadhan (Maughan, Fallah and Coyle, 2010; Lessan and Ali, 2019; Levy and Chu, 2019). Nevertheless, this area of research has progressed to a number of studies examining IFast protocols, including Time Restricted Eating/Feeding (TRE/TRF), Alternative Day Fasting (ADF) or observing a combination of both. More recent studies have engaged in investigating the effects of IFast in resistance training in conditioned athletes or healthy exercisers. Naturally, these studies were also preceded by a number of pre-clinical studies that investigated IFast for effects on endurance performance in rodents (reviewed in Chapter 2).

The present study applies elements of the research to-date by investigating the effects of IFast in the form of a 16:8 TRE protocol on nutrient intakes, body composition, indices of running performance, and markers of metabolic health in male endurance athletes. The present study is the first to investigate the effect of a period of IFast in the form of 16:8 TRE in an endurance-trained population.

As is often the case with emerging practices in sport science, in contrast to the limited studies to date in the scientific literature, a high number of articles on IFast have been published in well-known running websites, blogs and social media outlining the benefits, and in some cases the drawbacks, of chronic adherence to IFast. Anecdotally, the benefits outweigh the negatives and thus has accelerated popular opinion in favour of IFast as another valuable tool in the arsenal of the middle- to long-distance runner. However, the following articles forgo endorsements and more inform on strategies that are deployed in IFast; Triathlete.com asks the question, "Is Intermittent Fasting a good idea…" where the author, Matt Fitzgerald, suggests that whilst there is evidence in the research of effective weight loss, he dissuades this practice suggesting that traditional weight-loss methods provide similar outcomes to IFast and the usage of fat as a fuel source (as a consequence of exercise in the fasted state) has no beneficial effects on performance (Fitzgerald, 2016). Another article, this time on the mapmyrun.com blog, asks the same question where the author, Molly Hurford, introduces her thoughts with a summary of results from pre-clinical and human studies concluding that weight loss and other health benefits were observed, but that other studies have showed negative impacts on performance for athletes observing Ramadhan (Hurtford, 2018). In the article Dr Stacy Sims is quoted as asking "…why someone would need to do intermittent fasting in the first place?". She explained that our daily eating behaviours expanding to a greater percentage of the day as having an adverse effect on digestive and metabolic health. She recommends a more balanced approach to IFast where "normal eating" becomes the diet protocol, and a prolonged break of 10-12 h in each day (as opposed to 16 h in 16:8 TRE) with good eating practices such as fuelling prior to training and lessening carbohydrate intake during late evening.

It is important to consider why there exists the current enthusiasm with IFast in sports and fitness and why it has gained popularity. Exercise, nutrition, and training have operated parallel for many years in elite sports and especially where major multi-annual events like the Olympics and world championships become the endgame (Burke and Hawley, 2018). However, prescribed nutrition interventions and dietary approaches have grown in popularity amongst fitness enthusiasts too and are no longer just in the realm of elite athletes. In fact, dietary guidelines, and the role of therapeutic dietary interventions, have become integrated into the well-being of society as an awareness in metabolic diseases and health is also on the increase and undoubtedly linked to dietary intakes.

Two IFast protocols of the greatest popularity in recent times are the so-called "Leangains Method" and the "Warrior Diet", both of which have in fact been investigated in the peer-reviewed literature described in more detail in Chapter 2. Leangains was introduced by Martin Berkhan in the early 2000s as a means to potentiate muscle hypertrophy in response to training and increase whole-body fat oxidation at the same time. Ultimately, he proposed IFast as being suitable for increasing lean body mass and reducing fat mass (Berkhan, 2018). Leangains uses a 16:8 h fasting/feeding structure in each 24 h cycle with specific nutrient requirements for high protein intake. Anecdotally, this IFast protocol has been favoured by bodybuilders and resistance-trained athletes. The Warrior Diet, created by Ori Hofmekler in 2001, was designed to improve habitual eating behaviour, functioning and performance by stressing the body through reduced food intake, thus triggering "survival instincts (Hofmekler, 2007). The Warrior Diet is an IFast protocol that engages a 20 h fasting or an extreme caloric deficit combined with a 4 h period of overeating usually observed in late evening. During the fasting time, dieters are encouraged to consume small amounts of dairy products, hard-boiled eggs and raw fruits and vegetables, as well as plenty of non-calorie fluids. While the apparent interest in the concepts is evidenced by the respective websites and best-selling books of these authors, to a large extent there remains an absence of peer-reviewed studies on IFast protocols in athletes.

The world of elite running is fascinating, no more so than in a competition year such as the Olympics or World Athletics championship. Athletes will spend years perfecting their training to determine small improvements in their performance. Whilst this may seem peculiar to most, most active runners can relate to these extreme pursuits. From my own perspective as a club and marathon athlete and practising running coach, I am bought into this world of performance and personal bests. I have spent many years adopting and adapting training plans to attain that sub-three hour mark for 42.195 km. In the past, the volume of physical training was seen as the primary determinant for improved performance but now we know that it is more complex than the accumulation of weekly training sessions. Nutrition has now become one of the pillars for improved performance and is inextricably linked with appropriate training, recovery and many other fundamentals that produce the best athletes and allow athletes to reach their full potential (Burke and Hawley, 2018).

As IFast has become of greater interest within the community of athletes with whom I run and coach, my motivation for the study was to investigate the potential effects of IFast on the performance of athletes engaged in endurance training. Upon completing my review of literature (Chapter 2), it was clear that despite the popular trends described above, research to-date has not thoroughly investigated if IFast, regardless of the protocol, elicits any changes in body composition or indices of endurance performance in endurance athletes. Whilst several studies have shown consistency in the benefits of weight loss and other metabolic health markers in response to IFast, these do not apply to athletes and therefore, more studies are needed to evaluate outcomes of specific IFast protocols across sporting disciplines. Therefore, the present thesis investigates the effect of 8 weeks of 16:8 TRE, when combined with habitual exercise training, in a group of trained middle- and long-distance male runners.

2 Chapter Two: Literature review

The most recent American College of Sport Medicine (ACSM) Position Stand on Nutrition and Athletic Performance (American College of Sports Medicine and Academy of Nutrition and Dietetics Dietitians of Canada, 2016) is notable for its evolving perspective towards a more nuanced and personalised approach to performance nutrition that recognises that nutrition requirements are not static. In fact, nutrition requirements and strategies must reflect both the needs of daily training sessions and performance, as well as an individual's body composition [principally fat and lean body mass (LBM) or fat-free mass (FFM)[1]], health, and performance goals. An important concept in this regard is nutrition "periodisation", and its role in supporting the optimisation of body composition, fuelling and performance.

2.1 Periodisation of nutrition in sport

Periodisation, in the context of exercise training refers to "the logical and systematic process of sequencing and integrating training interventions in order to achieve peak performance at appropriate time points" (Haff and Triplett, 2017). In recent years, there has been the emergence of the concept of nutrition periodisation, which in the broadest sense posits adaptations, initiated by exercise, that can be amplified or diminished by nutrition. Therefore, the term nutrition periodisation can be used to describe changes in nutrition intake in response to certain periods of training or

[1] Throughout this thesis I will refer to FFM rather than LBM or muscle mass even though these terms are often used interchangeably (but obviously differ in the components of body composition that they measure). In studies to date in the IFast literature concerning athletes and active adults, it is FFM that has been the measure most commonly used and the measure that I report in Chapter Three.

phases of the season (Stellingwerff, Boit and Res, 2007). More recently, a more formal definition of nutrition periodisation has been proposed as “the planned, purposeful, and strategic use of specific nutritional interventions to enhance the adaptations targeted by individual exercise sessions or periodic training plans, or to obtain other effects that will enhance performance in the longer term” (Jeukendrup, 2017). Nutrition periodisation uses planned nutritional strategies to enhance periods of training and furthermore to target adaptations over long-term performances. In 2007, the International Association of Athletics Federations (IAAF) Nutrition Consensus presented the first formal opportunity to provide theoretical guidelines for nutrition periodisation, with suggestions of the approximate energetic and macronutrient demands of different training phases within a yearly periodised training plan (Stellingwerff, Boit and Res, 2007).

Whilst nutrition periodisation has somewhat become a “cause celebre” over the past decade, most obviously with the manipulation of carbohydrate intakes in the so-called “train low, compete high” paradigm (Impey *et al.*, 2018), further studies are required to ascertain best practices and establish the most applied frameworks and approaches. Using the train low, compete high paradigm as an example, this approach involves training sessions undertaken with reduced CHO availability such as fasted exercise and two-a-day training where carbohydrate is restricted between the two training sessions. These nutrient manipulations are performed in order to elicit greater stimulation of molecular pathways that regulate skeletal muscle adaptation such as the AMP-activated protein kinase (Impey *et al.*, 2018). In contrast to training “low”, high intensity training sessions and competitive performance are undertaken with high CHO availability such as best practice guidelines for increasing muscle glycogen and provision of exogenous CHO during exercise in order to maximise performance (Impey *et al.*, 2018). However, while at present there is plenty of evidence that these manipulations can impact acute molecular responses and performance within training sessions, the evidence that such approaches augment training adaptations over traditional sports nutrition guidelines remains equivocal (Gejl and Nybo, 2021). For most athletes, adherence to a training programme (training periodisation) may be easily pursued, whereas nutrition requirements in a programme are sometimes overlooked until pre-competition days, allowing for a crucial element of the training build-up phase to be omitted. Nutrition should be apace with training and should be planned with specific nutritional goals to accompany each specific training session. Understanding how to plan and practice the periodisation of nutrition could greatly enhance performance (Stellingwerff, Maughan and Burke, 2011; Jeukendrup, 2017)

Various methods have been discussed to optimize training adaptations and some of these methods have been subject to extensive study. To date, most methods have focused on skeletal muscle, but it is important to note that training effects also include adaptations in other tissues (e.g., brain, vasculature), improvements in the absorptive capacity of the intestine, increases in tolerance to dehydration, and other effects that have received less attention in the literature. In addition to train low or train high, methods have been developed to train the gut (to tolerate higher exogenous CHO intake), train in a hypo-hydrated state (to reduce the negative effects of dehydration), and train with various supplements that may increase the training adaptations longer term e.g., creatine, beta-alanine (Jeukendrup, 2017; Stellingwerff, Morton and Burke, 2019). Therefore, appropriate practical application lies in the optimal combination of different nutritional training methods as part of a periodised plan. Some of these methods have already found their way into training practices of athletes, even though evidence for their efficacy is sometimes scarce at best. Which of these methods should be used depends on the specific goals of the individual and there is no method (or diet) that will address all needs of an individual in all situations, and hence the need for periodised plans.

The sport of athletics, respectively track and field, has an explicit pathway to training as a result of structured seasons and a fixed number of high-end competitions. The concept and underpinnings of periodisation are therefore unsurprisingly established in the history of athletics. During the mid-20th century, the critical scientists and coaches who pioneered the principles of periodisation include Dr Hans Selye who applied his General Adaptation Syndrome model (Selye, 1950), followed by Matveyev, Bonderchuck, and Bompa, whose further contributions have been acknowledged as key elements in the development of periodisation concepts and practice. These developments are beyond the scope of this thesis given my specific focus on nutrition, but have been reviewed in detail elsewhere (Issurin, 2010; Stellingwerff, Morton and Burke, 2019). Importantly, a number of approaches to periodisation have emerged from these works including classical, block and polarised models, yet it is worth noting that there remains an underappreciated complexity associated with producing predictable performance on demand (Stellingwerff, Morton and Burke, 2019). For the individual athlete, competition is at the core of their mindset, thus every opportunity in preparation for an event harnesses every resource available that can be used to gain the competitive edge.

In theory, this structure makes athletics an ideal sport to use nutrition periodisation. In particular, middle- and long-distance running place vast biomechanical and energy demands on the body during training, pre-competition and on race day. Therefore, a better understanding of the role that nutrition plays in adaptations to training, performance and recovery continues to require many investigative research studies. Nutrition periodisation can be conceptualised in simple terms as focusing either on optimising the way in which the body utilises fuel during exercise, and/or optimising adaptations to training functioning as changes in body fat or FFM. I propose that based on the current, albeit limited evidence, that IFast, and specifically TRE, is a form of nutrition periodisation that has the potential to alter fuel utilisation during exercise and improve body composition over the long term.

2.2 *Nutrition periodisation to alter substrate utilisation*

An important consequence of exercise training is to elevate metabolic pathways to increase the power (rate of synthesis) and capacity (amount) of adenosine triphosphate (ATP) utilised in the muscle cells, and to attenuate mechanisms that restrain these pathways (Egan and Zierath, 2013). Fundamentally, these metabolic pathways can be enhanced by increasing the size of the storage and availability of endogenous fuels and enhancing the body's ability to utilise both endogenous fuel stores, and exogenous fuels consumed pre- and during exercise. Furthermore, the increased delivery of oxygen and nutrients to active muscles can enhance metabolic efficiency and reduce accumulation of by-products that may inhibit cellular homeostasis or metabolic regulation in the production of ATP during exercise at intensities at or above lactate threshold (Egan and Zierath, 2013).

Carbohydrate (CHO), stored as muscle glycogen and/or circulating as blood glucose, provides an effective and dominant fuel source for performance in many athletic disciplines that require efforts above moderate intensities (Hawley and Leckey, 2015). In comparative terms, ATP provision entirely from CHO produces approximately 6% more ATP per litre of O_2 consumed compared to ATP provision entirely from fat (Krogh and Lindhard, 1920), whereas the rate of ATP resynthesis from CHO sources is greater than in fat (Hawley and Leckey, 2015). These concepts of “efficiency” and “power” of ATP synthesis, respectively, explain why CHO is the “go-to” fuel source for athletes who train and race in endurance events for a sustained period of time, such as middle distance, long-distance and marathon runners. In simple terms, CHO gives better energy return to the athlete when needed. Therefore, high CHO (glycogen) stores in muscle tissue provide adequate fuel for training sessions but also are the key nutritional needs for competition. In addition to promoting training quality, undertaking sessions with high CHO availability can enhance the pathways of oxygen-independent glycolysis and CHO oxidation (Cox *et al.*, 2010). However, it is also important to note that CHO stores are somewhat small and limited in the context of ATP provision for exercise compared to the more abundant nature of the body’s fat stores. In fact, inadequate or depleted CHO stores can be limiting to endurance performance. Therefore, there is much interest in training the body to be able to transition between the efficient use of fat and CHO when needed and when the demands arise (Impey *et al.*, 2018).

On a related theme, manipulation of muscle glycogen stores, circulating CHO availability in the form of glucose, and plasma free fatty acid concentrations can also regulate many adaptations in the body, specifically amid endurance exercise, and alter the contributions of CHO and fat to energy provision during exercise (Hansen *et al.*, 2005; Yeo *et al.*, 2008; Morton *et al.*, 2009; Hulston *et al.*, 2010). One such example is adherence to low CHO or ketogenic diets, which although increasing the percentage contribution of fat to energy provision, do not always increase performance over multi-hour endurance events, and in fact can diminish performance in events of shorter than 90 minutes (Burke, 2015). Exercising in the fasted state results in a similar pattern of substrate utilisation during acute exercise under conditions of low CHO or ketogenic diet in that rates of fat oxidation and the percentage contribution of fat to energy provision are both increased compared to the fed state (Bergman and Brooks, 1999). Therefore, due to the similar metabolic responses to exercise in low CHO diets and IFast, if exercise training was to be performed in the fasted state in the latter, it is plausible to assume similar training-induced outcomes on energy provision during exercise. Whilst there may be an increase in rates of fat oxidation during exercise, and/or overall capacity for fat oxidation within the body, CHO will inevitably be the predominant energy source during high intensity training or competition.

However, training while in the fasted state during IFast protocols may improve metabolic flexibility (the transition between fat and CHO for energy provision) and/or alter the balance of fat and CHO utilisation at the same intensity of exercise in the fed state, however to-date this has only been demonstrated in pre-clinical studies (see Section 2.7). Mechanistically, this is explained by exogenous CHO intake resulting in the attenuation of rates of fat oxidation during exercise. Conversely, a large number of studies show that use of fat sources including both circulating free fatty acids intramyocellular lipid (IMCL) for energy provision is considerably enhanced during exercise in a fasted state (Van Proeyen *et al.*, 2011). The suggestion is that TRE may also reflect these outcomes if the prescribed exercise is performed in the overnight fasted state, and a higher percentage of fat oxidation is utilised for fuel energy. As stated above, a consequent training outcome may be that the body better transitions between fat and CHO utilisation as observed in "train low, compete high" paradigm where most training takes places in acute fasted states or with a low CHO intake and/or availability. However, it must be said that whether an individual athlete's training would take place in the fasted state would be dependent on the time of day at which they train and whether they practice "early" or "late" TRE, which reflect early dinner or late breakfast, respectively, as a means to shorten the eating window each day.

2.3 Periodisation of Energy Intake

Energy intake (EI) describes the energy, measured in kcal or kJ, that is obtained from foods and fluids ingested in the diet, with the total amount of calories consumed over the course of 24 hours normally referred to as daily calorie intake or calorie consumption. Athletes often employ strategies to manipulate EI in order to obtain a more desirable body composition for their sport by reducing body mass and/or body fat, and/or to gain or maintain muscle mass or FFM. However, there may be a risk to physical health and performance if appropriate guidelines are not adhered, especially through excessive energy deficit or low energy availability (Logue *et al.*, 2020). Changes in EI should be strategically integrated into training periodisation (long- and short-term) to minimise the effects on training quality and/or competition performance (Stellingwerff, Morton and Burke, 2019). Stellingwerff et al. (2019) also note that while EI fundamentally is a consequence of the intakes of macronutrients, athletes must be cognisant that careful manipulation of diet as a function of EI in order to attain micronutrient objectives within restricted calorie and nutrient targets (Stellingwerff, Morton and Burke, 2019). As a part of a periodised training and nutrition strategy, EI can be strategically manipulated within the architecture of yearly training programmes to enhance training and competition at key junctures; hence the inclusion of EI as one of the cornerstones of nutrition periodisation. Examples might include provision of an energy surplus in order to facilitate gains in FFM through an optimal anabolic environment, or reductions in energy intake during pre-season training in order to decrease body mass that was gained in the off-season, or for chronic weight loss as part of a training camp for weight-category combat sports. One note of caution in the case of the latter two examples is the need to maintain adequate energy availability in order to avoid acute and chronic issues that are identified with low energy availability and Relative Energy Deficiency in Sport [RED-S] (Mountjoy *et al.*, 2018). That said, approaches to periodisation of body composition as a function of a training plan have been illustrated over different stages and within the confines of the effect of training adaption, health, and performance (Heydenreich *et al.*, 2017; Stellingwerff, 2018). One such example is a case study describing a history of body composition management of elite female middle-distance runners to outline a gradual increase in optimal physique over the career of the athletes underpinned by changes that take place during each competition season (Stellingwerff, 2018).

Essential to the consideration of EI is also consideration of energy expenditure, and the daily requirements as a result, which are often referred to total daily energy expenditure (TDEE). Energy expenditure is the sum of the basal metabolic rate (energy expended at complete rest), the thermic effect of food (TEF) (energy required for digestion and absorption), and the energy dissipated during physical activity or the energy expenditure of exercise (EEE). TDEE fluctuates for each athlete given that it is primarily dependent on the age, sex, stature, and body composition, but the most variable component is EEE given the wide-ranging demands of different sports and training activities. Therefore, periodisation of EI should reflect intake appropriate to meet the required TDEE over days, weeks, and months as appropriate. While Stellingwerff et al. (2019) have mapped out a framework for professionals to engage in periodisation of EI through an evaluation of total caloric estimations and substrate utilization for a series of training sessions, in practice without sophisticated equipment, it remains challenging to obtain exact measures of EI and TDEE (Burke *et al.*, 2018).

2.4 Intermittent fasting protocols

A spectrum of IFast protocols have been explored in recent human and pre-clinical studies. Leading protocols researched include Time-Restricted Eating (TRE)/Time-Restricted Feeding (TRF), Alternate-day Fasting (ADF), and the so-called 5:2 diet but are not limited to these. Both TRE and TRF apply the same protocol/principles; however, in context, TRF is associated with pre-clinical studies due to the "feeding" of animals, whereas TRE is so chosen because of the activity of "eating" in humans. The most accepted practices within these protocols include restrictions in calorie intake, designated fasting duration, and eating times (eating window) with either prescribed or *ad libitum* food intake. The majority of studies in IFast to-date have researched short-term interventions of 4-to-8-weeks in human participants, whereas more long-term studies have been carried out in pre-clinical trials in rodents (see Section 2.7). The extent of studies on weight loss have explored the effect of hypocaloric diets in the confines of what is termed continuous energy restriction (CER) i.e., a consistent daily energy deficit to bring about weight loss. However, in recent years, dietary intervention for weight loss has also included investigation on undulating restrictions in calorie intake, with adjustments in the duration of energy restriction and periods of unrestricted eating being interspersed (Katsarou, Katsilambros and Koliaki, 2021). This approach is referred to as intermittent energy restriction (IER).

It can be difficult to parse out IFast protocols as being either CER or IER because TRE/TRF, ADF and 5:2 diet practices can each result in CER or IER. However, IER is adopted through religious practices such as Ramadhan where total fasting is observed between sunrise and sunset for a lunar month (28-29 days) in the Muslim faith. These practices have been observed for centuries where the benefits have been recorded in a number of recent studies (Bouhlel *et al.*, 2006, 2008; Javad Fallah, 2010; Stannard, 2011; Burke and King, 2012; Chaouachi *et al.*, 2012). Many contemporary IFast protocols may have been inspired by these and other age-old practices. Due to the many interpretations in the literature and insufficient nomenclature of fasting protocols, this thesis will outline the most commonly deployed protocol strategies in the following summaries.

2.4.1 Time-Restricted Eating/Time-Restricted Feeding

Both TRE/TRF are based on fasting and eating (feeding) that occurs within a 24 h cycle, and where the most accepted practices are generally the 16:8 or 20:4 fasting/eating protocols. In colloquial terms, these are often referred to by the names of the books that initially popularised them i.e. the Leangains Method and Warrior Diet, respectively, as mentioned in Chapter 1. Large variations can also exist within these practices, especially where features of the fasting period (fasted state) and the eating period (fed state) have been altered to achieve the desired outcomes. For example, 16:8 TRE protocols in recent studies have prescribed features such as a calorie deficit as part of a controlled diet, prescription of powdered protein supplements, or the addition of the nutrition supplement β-hydroxy β-methylbutyrate (HMB), a metabolite of the essential amino acid leucine (see Section 2.5) or allowed eating *ad libitum*, but confined to a required daily eating window.

It is noteworthy that these popular IFast protocols preceded the emergence of a scientific evidence base around the application and outcomes of various IFast protocols. Leangains Method creator Martin Berkhan had first introduced the 16:8 pattern in his diet protocol in the mid-2000s where fasting commenced shortly after the last evening meal and continued into the next morning followed by commencement of an 8 h eating window at mid-day. As this diet was introduced in the domain of resistance exercise training, daily protein supplementation in the form of BCAAs or EAAs was also prescribed (Berkhan, 2018). The Warrior Diet takes a different approach where participants are expected to fast during the day and overnight with a 4 h eating window in the evening time where food intake is *ad libitum,* and no restrictions are given on macronutrients. Additionally, with this diet, small quantities of protein-rich foods can be consumed during the fasting period, which of course is paradoxical to the term fasting, but are suggested to improve the anabolic potential of the diet (Hofmekler, 2007). As stated above, variations in the TRE/TRF protocols do exist, and are largely dependent on the desired outcomes of diet in relation to training in practical settings, or as determined by the study design and research question(s) in experimental settings.

2.4.2 Alternate-day fasting

Another periodically applied fasting protocol, and therefore a version of IER, is the alternate-day fasting (ADF) protocol in which daily energy intake is dramatically reduced (by up to 75% of energy requirements) or entirely omitted on non-consecutive days of the week (Varady and Hellerstein, 2007). ADF is also known as the “every other day diet” (EODD) in the public domain or has been referred to as “every other day fasting” (EODF) in some rodent studies. Generally, energy intake on eating days may vary from 1500 to 2500 kcal for females and 2500 to 3500 kcal for males, consistent with daily energy requirements in these cohorts. Some studies in IER have shown results in weight loss between 4 and 10% over 4–24 week periods, depending on the diet protocol used (Katsarou, Katsilambros and Koliaki, 2021).

2.4.3 The 5:2 diet

Another version of IFast that manifests as IER is the 5:2 protocol, also termed periodic fasting, according to which energy intake is targeted to 500-600 kcal (but sometimes 0 kcal) during each of the two non-consecutive weekdays of energy restriction, while during the remaining five weekdays energy intake returns to *ad libitum*. However, it is also the case that there are different versions/interpretations of the 5:2 protocol. The classic version of the 5:2 diet is as described above entailing choosing two days of the week on which to eat lightly (500 to 600 kcal) and eating normally on the other days. Another version entails choosing two days of the week on which to eat normally, and then performing 16:8 TRE on the other five days. The obvious difference between these two versions is the emphasis in terms of proportion of days of the week where some form of fasting is taking place.

2.5 Current research on IFast in the form of TRE in athletes & active adults

Even though there is considerable interest in IFast within the health and fitness communities and numerous websites, blogs and diet books exist, only a small number of studies have examined these approaches in athletes and active adults, and in fact the vast majority of research has been in the context of metabolic disease (Anton *et al.*, 2018). Given the relevance to my research question, I will therefore focus on studies to date in athletes and active adults in this section of the literature review, and the following article summaries outline the study design, participation, and results of the most informed research of the effects of IFast in these cohorts. At the time of writing this literature review alongside the development of the manuscript for peer-review that forms Chapter 3, only four studies of IFast had been performed in humans who were athletes or active adults performing regular exercise, and each of these involved resistance, rather than aerobic, exercise (Moro *et al.*, 2016; Tinsley *et al.*, 2017, 2019; Stratton *et al.*, 2020). Table 1 provides a tabulated summary of these studies including relevant data not detailed in the main text below. Relevant research published since the completion of this literature review and acceptance of Chapter 3[2] in the peer-reviewed literature will be summarised in Chapter 5.

In the first study, to my knowledge, that examined IFast in the context of athletes or active adults, Moro et al. (2016) investigated the effects of TRF[3], using a 16:8 protocol, on basal metabolism, maximal strength, body composition, inflammation, and cardiovascular risk factors in resistance-trained male athletes. A total of 34 male participants were assigned to a TRF (n=17) or normal diet (ND) (n=17) group and were tested over an eight-week intervention where TRF participants consumed 100% of their energy intake in three meals allocated at 1pm, 4pm and 8pm (~8 h eating window), and abstained from nutrient intake for the remaining 16 h of the day. ND consumed 100% of their daily energy intake at the prescribed mealtimes of 8am, 1pm and 8pm i.e., ~12

[2] Chapter 3 was originally submitted to *Medicine and Science in Sport and Exercise* in June 2020, accepted in August 2020, and published in March 2021 as Brady AJ, Langton HM, Mulligan M, Egan B. Effects of 8 wk of 16:8 Time-restricted Eating in Male Middle- and Long-Distance Runners. Med Sci Sports Exerc. 2021 53(3):633-642. doi: 10.1249/MSS.0000000000002488.

[3] For the purposes of this review section, I will use the nomenclature/terminology used by the authors of the respective papers at the time of publication of their work. For example, here TRF was the term used by the authors even though, as described in above, TRE is now more commonly applied to humans and TRF is used to refer to rodent studies as described in Section 2.7.

h each of fast and eating window. These times were chosen to create a balanced distribution of meals in the eating window of the TRF group, and a “normal” intake and timing of meals (breakfast, lunch & dinner) in the ND group.

As a result of the intervention, there was a significant decrease in fat mass (FM) in the TRF group (−1.61 ± 1.53 kg), whereas changes in FM in the ND group were non-significant (−0.30 ± 1.70 kg). Fat-free mass (FFM) was maintained in both groups (+0.86% and +0.64% for TRF and ND, respectively). The intervention also produced significant decreases in glucose, insulin, testosterone, and IGF-1 concentrations in blood in the TRF group, but with no significant change in the ND group. A significant increase in leg press maximal strength was observed for both groups during the intervention.

Groups were matched for calorie and macronutrients prescribed by a dietician and training was standardised between groups. Therefore, a key observation was the difference observed in fat mass (i.e., greater loss in TRF) occurred even though daily calorie intake was matched, and only the duration between meals/length of the eating window were modified. The mechanism to explain this effect remains to be lacking and it also remains an open question as to the effects of allowing *ad libitum* food intake but within a short eating window as opposed to the prescribed nature of the diet employed by the researchers. Nevertheless, Moro et al. was the first study to provide an in-depth investigation of IFast in an athlete population and demonstrated beneficial effects on fat loss, while resulting in no apparent loss of FFM or decrement in the adaptation to training in leg strength.

Another study from the same research group was published a year later wherein Tinsley et al. (2017) conducted an eight-week randomised control trial to investigate resistance training (RT) and TRF in recreationally active young males (age, 22.0 ± 2.4 y) to evaluate nutrient intake, adaptations in body composition and muscular health. Participants were randomly selected for a TRF or normal diet (ND) group and commenced a new training programme i.e., with no previous RT experience in contrast to the previous study. The TRF group consumed their daily energy intake (no limitation on kcal and types of food consumed) within a 4h window (anytime between 4pm and midnight) for four days per week, whereas the ND group continued their habitual diet as normal. Therefore, while the work of Moro et al. (2016) was akin to the Leangains Method, this study mimicked the Warrior Diet, albeit only on 4 days of the week and these were the days on which the participants did not train. Both groups performed an RT programme consisting of upper and lower body workouts. Participants were observed at week 0, week 4 and week 8 of the study and a 4-day food diary was completed at each interval. Measurements of body composition by dual-energy x-ray absorptiometry and muscle cross-sectional area by ultrasound were obtained. Upper and lower body strength and endurance were assessed, and four-day dietary records were collected.

This study observed that energy intake was reduced on TRF days by ~650 kcal per day, but this difference did not produce differences in body composition in the RT-TRF group as a result of the intervention. In fact, no significant changes in body mass or body composition were observed in either group. However, despite the lack of statistical significance, a difference worthy of comment was noted in FFM in whereby RT-ND gained 2.3 kg as opposed to a loss of -0.2 kg in RT-TRF. This large variability observed, and the small sample size adopted in the groups may explain the absence of statistical significance. Despite the difference in calorie intake in the TRF group, and no changes in body composition, the authors suggested that there could have been spontaneous reductions in energy expenditure (e.g., decreased non-exercise activity thermogenesis).

Upper and lower body strength and lower body muscular endurance increased in both groups. Overall, TRF reduced energy intake and did not adversely affect muscular improvements with short-term RT in participants despite the large, albeit non-significant differences in change in FFM. However, the type of TRE employed in this study is worth noting again given that it is rather different to other approaches in that the eating window is very narrow at 4 h per day and was only applied on the four non-training days of the week.

Next, from the same research group Tinsley et al. (2019) conducted a randomised controlled trial of TRF in resistance-trained active females (age 18-30 y). A total of 40 participants were randomly assigned to TRF and control diet (CD). However, two TRF groups were assigned in the study where participants consumed a placebo (calcium lactate) or 3g per day of calcium HMB. However, for the purposes of this chapter and Table 1, only results from the TRF placebo group are reported, and only the per-protocol (PP) analysis is included for the 24 participants who competed the intervention.

TRF groups consumed their daily calorie intake between 12pm and 8pm, using a 16:8 IFast protocol. CD group consumed their daily calorie intake as normal. All participants were prescribed a 250 kcal energy deficit per day, and supplemented with whey protein on both training and non-training days to achieve a protein intake ≥1.4 g/kg/d. This method was used to increase protein intake to align with recommendations for individual lean mass retention, but should therefore be considered a high protein, calorie restricted diet as well as being IFast. All participants concluded 8 weeks of supervised RT performed over three non-consecutive days each week, and training sessions were altered between two different upper and lower body workouts.

Differences in energy and protein intake between groups (~1.6 g/kg/d) were negligible despite variation in the length of the eating windows (TRF ∼7.5 h/d; CD: ∼13 h/d), and ultimately TRF did not impair gains in FFM, skeletal muscle hypertrophy or muscular performance when compared with CD group. There was a significant decrease (group by time interaction) in fat mass in the TRF group compared to CD. However, despite fat mass being lower in week 4 compared to week 0 in the TRF group, there was no significant change in week 8 compared with week 0. No changes were observed in physiological variables in all groups, and minimal side effects were reported. Although there was no difference in calorie intake and prescribed exercise, a greater reduction in fat mass was observed in the TRF group, which is similar to that reported by Moro et al. (2016). Although again the mechanism is unclear as to how more fat mass was lost in the TRF group, this study was the first in females who were performing exercise training, and therefore notable that the intervention produced similar results to those seen in males (Moro *et al.*, 2016). However, despite the interaction effect observed and the lower fat mass at week 4, it should be noted that by 8 weeks, this difference between groups was no longer evident, which suggests either the change at 4 weeks was not robust, and/or adherence to the diet (or the metabolic effect of the diet on fat mass, if any) is reduced beyond 4 weeks. Lastly, Stratton et al. (2020) investigated a 4-week TRF intervention adopting a 16:8 IFast protocol in recreationally active males (ages 18-35 y), who were already engaged in resistance training. Twenty-six participants were randomly assigned to a TRF or normal diet (ND) group. Both groups consumed 1.8 g/kg/day of dietary protein to promote adaptations in FFM to resistance training. The

TRF group consumed their energy intake between 12-8pm or 1-9pm with a prescribed 25% caloric deficit. Normal Diet (ND) group consumed their daily intake *ad libitum* with a prescribed 25% caloric deficit. Therefore, like Tinsley et al. (2019), the dietary intervention included high protein intake and an energy deficit.

No significant difference was observed in total calorie intake (TRF 1946 ± 310 v ND 1939 ± 260) between groups. From pre- to post-intervention, body mass, fat mass and body fat percentage decreased in both groups, but FFM remained unchanged. However, no group × time interactions were observed for body mass, fat mass, FFM and body fat percentage. Resting energy expenditure and muscular performance (vertical jumps, leg press strength and bench press strength) increased over time, but again no group x time interactions were observed.

Stratton concluded that adopting a TRF fasting protocol does not lead to greater reduction in fat mass compared to the reduction in fat mass on a normal calorie restricted diet with the same percentage of a calorie deficit. Importantly TRF did not impair the retention of FFM or gains in muscle strength produced by training during this time. One could observe that a 4-week intervention is short, thus research attained over longer timeframes may provide better analysis. Furthermore, there is no evidence of reporting adherence to the daily eating window in the TRF group and the dietary intake were self-reported, which require participants to accurately report their intake. Therefore, longer interventions and better reporting of adherence and intakes are important study design features for future work.

2.5.1 Reliability and sensitivity of methods of assessment of change in body composition

Because the aforementioned studies often describe rather small changes in components of body composition, an important consideration is the reliability of these tools. Body composition in these studies (Moro *et al.*, 2016; Tinsley *et al.*, 2017, 2019; Stratton *et al.*, 2020) was measured using dual x-ray absorptiometry (DXA) whole body scans, yet none of these studies reported reliability estimates from data collected in those studies. However, DXA is often considered either the gold standard or the criterion method for measuring body composition, and is widely used in clinical assessment (Laskey, 1996) and sport (Nana *et al.*, 2015), and therefore the reliability of DXA measurements of fat mass and FFM (or LBM) in athletes have been the subject of prior work. Reliability coefficients are typically extremely high (R^2>0.98), and the coefficient of variation (CV) for fat mass and FFM are typically less than 3% (Zemski *et al.*, 2019). Similarly, the sensitivity as determined by the technical error of measurement have been found to be 0.25 kg and 0.52 kg in females and males, respectively, for fat mass, and 0.24 kg and 0.42 kg for females and males, respectively, for FFM (Kutáč, Bunc and Sigmund, 2019). All of the pre-to-post intervention changes in fat mass or FFM cited in Table 2.1 exceed these thresholds for sensitivity. The key feature to minimise error in measurement of body composition is the standardization of subject presentation by having subjects rested, overnight-fasted and in minimal clothing (Nana *et al.*, 2015). Importantly, again such practices were evident in each of the aforementioned studies (Moro *et al.*, 2016; Tinsley *et al.*, 2017, 2019; Stratton *et al.*, 2020). Taken together, these data and methodology are indicative of meaningful changes in body composition in response to IFast interventions.

2.6 Summary of studies to date on athletes and active adults

In summary, studies in IFast to-date in athlete or active adults has primarily investigated changes in body composition and muscle strength amid resistance training (Moro *et al.*, 2016; Tinsley *et al.*, 2017, 2019; Stratton *et al.*, 2020). Broadly speaking, IFast in the form of 16:8 or 20:4 TRE does not appear to impair the adaptive response to resistance exercise training in terms of increases in strength, FFM, or the retention of FFM in a calorie deficit. There are some indications for greater loss of fat mass with TRE compared to normal diet, at least when combined with resistance exercise training. However, given some doubts about the robustness of those data, and the absence of a physiological mechanism to explain the difference, this observation requires further investigation.

Table 2.1. Table summary of current research on IFast in the form of TRE in athletes and active adults.

Author (year)	Study design	Participants	Details of TRE/TRF	Outcomes related to dietary intake	Outcomes related to body composition	Outcomes related to performance
Moro et al, 2016	**8 wks. Intervention** **Parallel group pre-post design** 34 males randomly assigned to TRF (16/8; n=17) or normal diet (ND; n=17) Training was standardised for both groups, with 5 yrs of continuous RT. 3 sessions per week over 8 weeks Participants tested in weeks 0 & 8	**Male (n = 34)** Resistance-trained males with 5yrs training, 3-5 days/week (incl. 3yrs of split routines) **TRF group (n=17)** Age 29.9 ± 4.1 BMI 26.5 kg/m^2 BF% 13.0% **ND group (n=17)** Age 28.5 ± 3.5 BMI 27.2 kg/m^2 BF% 13.2%	TRF (16/8) protocol **Intervention (TRF group)** 16h fasting/8h feeding window, 100% of energy intake consumed in 3 meals at 1pm, 4pm & 8pm. 20g whey protein consumed after each training session **Control (ND group)** 100 % of energy intake consumed in 3 meals at 8am, 1pm and 8pm 20g whey protein consumed after each training session Groups were matched for kcal and macronutrients Dietary intake was measured before the intervention and participants were prescribed to maintain this intake during the 8 weeks, but to follow the above timings. Adherence to the diet protocol was checked regularly by a dietician	No significant difference was detected between groups and within groups **TRF group (baseline)** Total: 2826 ± 412.3 kcal/day % CHO 53.2 ± 1.4, % fat 24.7 ± 3.1, % protein 22.1 ± 2.6 **TRF group (Experimental)** Total: 2735 ± 386 kcal/day: % CHO 51.2 ± 3.6, % fat 25 ± 2.8, % protein 23.8 ± 3.1 **ND group (Baseline)** Total: 3007 ± 444.7 kcal/day % CHO 54.7 ± 2.2, % fat 23.9 ± 3.5, % protein 21.4 ± 1.8 **ND group (Experimental)** Total: 2910 ± 376.7 kcal/day % CHO 55.3 ± 4.2, % fat 22.6 ± 3.2, % protein 22.1 ± 3.2	Significant decrease in FM was observed in TRF group pre and post intervention, whilst non-significant in ND group (-16.4% vs -2.8% in ND group) **TRF** ↓ 1.6 kg **ND** ↓ 0.3 kg FFM was maintained in both groups pre and post study, ie. non-significant: **TRF group** (↑ 0.6 kg) **Pre** 73.08 ± 3.88 **Post** 73.72 ± 4.27 **ND group** (↑ 0.5 kg) **Pre** 73.98 ± 3.59 **Post** 74.41 ± 3.59	Significant increase was observed in leg press maximal strength, however no difference between treatment: **Leg-press 1RM (Kg)** **TRF group** Pre 282.8 ± 30.11 Post 290 ± 27.77 **ND group** Pre 298.6 ± 25.76 Post 309 ± 68.94 Blood glucose and insulin levels decreased significantly in the TRF group: **Glucose** (mg/dL) - Pre 96.64 ± 5.1; Post 85.92 ± 7.1 **Insulin** (mU/mL) - Pre 2.78 ± 0.6; Post 1.77 ± 0.9 The same trend was observed for arm and thigh muscle cross-sectional area

Tinsley et al, 2017	**8-week** **randomised controlled trial** 2 groups (ND and TRF) Participants were randomised to 8 weeks Resistance Training (RT) and normal diet (RT-ND) or 8 weeks of RT Time Restricted Feeding (TR-TRF) Both groups performed RT x 3 per/week on non-consecutive days	**Male (n = 28)** Untrained participants: Recreationally active, healthy men with no RT programme in the past 3 months **Groups:** **TRF (n = 14)** Age 22.9 ± 4.0 BMI 27.2 kg/m^2 BF% 21.3 ± 5.4 **ND (n = 14)** Age 22.0 ± 2.4 BMI 24.3 kg/m2 BF% 18.7 ± 3.8n 18 participants were included in the analysis (10 in TRF group, 8 in ND group)	**Intermittent TRF (20:4)** **TRF group** On the 3 days of RT, participants were allowed unrestricted food intake (*ad libitum*). On non-workout days (4 days), participants consumed all food intake in a 4-hr feeding window between 4pm to 12am. Daily checklists were taken to assess adherence to TRF days. **ND group** Participants in the control group were instructed to follow their habitual dietary patterns	**Dietary intake in RT-TRF group** Energy (kcal) – Baseline TRF = 1631 ± 563 U = 2318 ± 977 Energy (kcal) – Week 8 TRF = 1674 ± 745 U = 2150 ± 492 TRF – Restricted, U – unrestricted RT-TRF group consumed fewer calories (less CHO, protein, and fats) on fasting days. 667kcal were less consumed (CHO less 75g, protein less 30g, fat less 25g) on fasting days. There was no significant difference in the % of energy taken from each macronutrient between fasting & non-fasting days.	No significant changes in body mass (BM) or total body composition (MM and BF) were observed in both groups.	Hip sled and bench press strength, determined by 1-RM, increased in both groups over the course the 8 weeks, but no significant difference was observed between groups (Interaction affect). **Bench press 1-RM (kg)** RT-TRF = ↑ RT-ND = ↑ **Bench press endurance (repetitions)** RT-TRF = ↑ RT-ND = ↑ **Hip sled 1-RM (kg)** RT-TRF = ↑ RT-ND = ↑**Hip sled endurance (repetitions)** RT-TRF = ↑ RT-ND = ↑

Tinsley et al, 2019	8-week randomised placebo-controlled trial Fractional factorial design **3 groups** Time Restricted Feeding (TRF) (n = 13) Time Restricted Feeding +HMB (TRF_{HMB}) (n = 13) Control Diet (CD) (n =1 4) TRF group double-blind for supplemented.	**Female, n = 40** **40** participants intention-to-treat Resistant trained (≧ 1 year with frequency of 2-4 sessions/week) BF less than 33% **TRF Group** n = 13 Age 23.3 ± 1.5 BMI 23.8 kg/m2 * BF% 28.4 ± 1.5% **TRF_{HMB}** n = 13 Age 22.3 ± 3.4 BMI 22.9 kg/m2 * BF% 28.7 ± 1.5% **CD group** n = 14 Age 2.6 ± 2.7 BMI 22.5 kg/m2 * BF% 29.3 ± 1.5%	**Time Restricted Feeding** (16/8 protocol) TRF and TRF_{HMB} Group consumed all kcal intake between 12pm and 8pm daily, fasting at all other times CD group to consume breakfast upon wake-up & all other meals taken at self-chosen times throughout the day Minimum dietary guidance given. Participants to consume prescribed protein on training and non-training days to equate ≧ 1.4 g/kg/d All groups were prescribed an energy deficit of 250Kcal based on their REE All groups completed 8 weeks of supervised resistance raining (RT), 3 sessions/week on non-consecutive days between 12-6pm, alternating upper and lower body sessions	Energy intake is statically significant in pre-intervention and during intervention Prescribed calorie deficit and increase in protein intake in all groups. **P(time) = 0.01** Significant difference protein intake in pre and during intervention. **P(time) = 0.0001**	FFM, MT_{EF}, and MT_{KE} incr. in all groups, no difference between groups in the ITT analysis. **TRF Group** FM ↓ 0.4 kg FFM ↑ 0.9 kg BF% ↓ 0.8% **TRF_{HMB}** FM ↓ 0.7 kg FFM ↑ 1.2 kg BF% ↓ 1.4% **CD group** FM ↑ 0.4 kg FFM ↑ 0.9 kg BF% ↑ 0.1% Reductions in FM for TRF relative to CD at specific time points. FM significantly lower at W4 than W0 in TRF. FM at W8 not significantly different than W0.	Maximal strength and muscular endurance improved in all groups without statistically significant differences between groups In both ITT and PP, RFD variables showed improvements in all groups, however, more consistent in ITT analysis. A p-value of .06 was observed for time main effect in all group in ITT, whereas no significant effects were observed in the PP analysis.

Stratton et al, 2020	**Parallel group design** Randomised into two groups Time Restricted Feeding (TRF) n = 13 Normal Diet (ND) n = 13 No significant weight loss (≥10% of BW) within 6 mos. of intervention and no prev. TRF practice.	**Male (n = 32)** (n=26 complete) Age: 18-35 years Recreationally active males Engaged in RT x 2-4/wk for 6mth. Participants free of orthopaedic injuries (5 years), no cardio, metabolic or pulmonary condts. **TRF group** n = 13 Age 22.9 ± 3.6 BMI 25.9 kg/m2 BF% 19.9 ± 8.3% **ND group (Control)** n = 13 Age 22.5 ± 2.2 BMI 26.4 kg/m2 BF% 18.9 ± 7.4%	Time Restricted Feeding (16:8 protocol) **TRF group** consumed all energy intake (EI) in 8h daily between 12-8pm or 1-9pm with a prescribed 25% caloric deficit. **ND group** consumed during normal feeding times with a prescribed 25% caloric deficit All participants consumed 1.8 g/kg/day of dietary protein (to promote optimal FFM adaptations) 50g of whey protein was consumed by all participants post-workout (during optimal nutrient timing) Remaining calories were distributed between CHO and fat intake *ad libitum* Both groups undergone 4 weeks of prescribed RT, performed 3 times/week. Training sessions occurred between 3-8pm during participant's feeding window	No significant difference observed between groups intake of protein. CHO and fats, total Kcal, and kcal/kg of bodyweight over the 4-week intervention: **Nutrient intake for TRF (g/kg)** Protein 1.83 ± 0.10 CHO 2.28 ± 0.71 Fat 0.84 ± 0.26 **Nutrient intake for ND (g/kg)** Protein 1.83 ± 0.07 CHO 2.25 ± 0.51 Fat 0.85 ± 0.22 **Total kcal** (p = .950) TRF = 1946 ± 310 ND = 1939 ± 260	Significant difference in time main effects for BM, FM, and BF% for both groups: **TRF group:** BM ↓1.2 kg FM ↓1.5 kg BF% ↓1.6% **CD group:** BM ↓1.4 kg FM ↓1.4 kg BF% ↓1.5% No group x time interactions were observed for BM, FM, FFM or BF%	**Vertical jumps:** No group × time interactions were observed for VJ_{HT}, VJ_{PP}, or VJ_{F}, however, time main effects were significant: **<u>VJ_{HT}</u>** (p=0.002) TRF ↑ 3.4cms ND ↑ 3.4cms **<u>VJ_{PP}</u>** (p=0.018) TRF ↑ 221.4 W ND ↑ 152.8 W **Strength & Endurance** Main effects for time were noted for LP_{1RM} ($p < 0.001$) and BP_{1RM} ($p < 0.001$). No group x time interactions were observed for either variable

2.7 Studies of IFast combined with exercise in rodents

Studies to date in humans of IFast in which exercise has also been performed have been in combination with resistance exercise training. In contrast, a number of studies have examined the effects of IFast combined with aerobic training in rodents (Chaix *et al.*, 2014; Marosi *et al.*, 2018; Real-Hohn *et al.*, 2018), and no studies have examined IFast intervention in human athletic populations undergoing aerobic training. Endurance athletes are always evaluating current trends in the training literature to enhance their running economy and performance, and a better understanding of the effects of IFast on metabolic pathways and fuel utilization, along with effects on body composition and muscular performance, may provide insights that augment improvements in aerobic training and endurance performance. However, the data in this domain at present are indirect, given that studies of this nature have only been performed in rodents.

In one study investigating IFast in the form of ADF for 4 to 7 weeks, researchers compared a control group to an ADF group, and exercise training group (EX), and an exercise training combined with ADF group (EXADF) (Marosi *et al.*, 2018). The results showed that ADF did not enhance increases in aerobic fitness in response to exercise training, thus changes in maximal oxygen uptake (VO_{2max}) were similar for EX and EXADF after 4 weeks of intervention. Improvement in endurance capacity measured in a time to exhaustion test was greater in EXADF compared to EX after 7 weeks of intervention. A glucose tolerance test performed in week 4 in the ADF and EXADF groups showed lower peak plasma glucose elevation and quicker recovery of glucose levels after glucose metabolism. The authors suggested that factors such as an upregulation of molecular pathways involved in mitochondrial biogenesis, and a shift towards greater contribution of fat to energy provision were part of the reason for the improved performance.

Another study in mice on a normal chow diet applying a treadmill run to exhaustion test, ran for 77±8 min. In comparison, mice on normal chow diet and performed a 5:2 IFast protocol for 12 weeks (15:9 TRF on 5 days of the week and *ad libitum* intake on 2 days of the week), ran 123±9 min until exhaustion (data are mean±SEM) (Chaix *et al.*, 2014). No mechanism was identified to explain this performance improvement, but the authors speculate that this effect was due to better ability to mobilise fuel stores. The study suggests that the benefits of TRF may be related to an increase in adipose tissue in different locations in the body, which could explain the use of different energy pathways during endurance exercise. Another relevant observation in the study showed that mice subjected to a 5T2A (5 days of time restricted feeding and 2 days of *ad libitum* feeding) protocol featured a gene expression signature to mice in the TRF protocol, despite a disconnection in their daily feed-fast behavioural rhythm during the eating weekend.

A final IFast study investigated a high intensity intermittent exercise protocol (HIIE) in the form of weight swimming in rats where a ADF fasting criteria was used (Real-Hohn *et al.*, 2018). The researchers compared the response to HIIE and IFast alone or in combination (IFast/HIIE) over the course of 8 weeks in comparison to a control group. No weight gain was observed in IFast alone HIIE protocols, but combined IFast/HIIE resulted in an increased in muscle mass measured by weight and muscle fibre size measured by cross-sectional area (both measured in the gastrocnemius muscle). A performance test using weighted swimming (12% bodyweight) until exhaustion revealed a higher endurance of rodents in the HIIE group being 90% greater than controls, but with the IFast/HIIE group being greater than the HIIE group and that was an approximately 180% improvement in time to exhaustion in comparison to the control group. Synergistic effects of IFast/HIIE compared to either IFast or HIIE alone were noted on hexokinase activity, ATP synthase activity and promoted mitochondrial coupling and biogenesis in skeletal muscle, which may each have contributed to improved exercise capacity (Real-Hohn *et al.*, 2018).

In summary, these pre-clinical studies, although small in number, do suggest a synergism between IFast and aerobic training adaptations such that their combination may augment the effects of exercise training on changes in body composition, substrate utilisation and exercise capacity, and provides a strong rationale for conducting the work described later in this thesis.

2.8 Summary of current literature and rationale for the presented experimental work[4]

Athletes and practitioners often pursue novel strategies regarding exercise training, nutrition, and recovery with the aim of enhancing performance in competition. Nutrition periodisation is a strategy that is of heightened interest in the last decade, with the manipulation of energy and macronutrient intakes suggested to modulate the adaptive response to exercise training, and consequently improve performance outcomes (Mujika *et al.*, 2018). IFast is one aspect of nutrition periodisation that is receiving increased scrutiny given its reported benefits on body composition and

[4] This section was previously published in March 2021 as the Introduction to the paper Brady AJ, Langton HM, Mulligan M, Egan B. Effects of 8 wk of 16:8 Time-restricted Eating in Male Middle- and Long-Distance Runners. Med Sci Sports Exerc. 2021 53(3):633-642. doi: 10.1249/MSS.0000000000002488.

markers of cardiometabolic health, independent of intentional caloric restriction (de Cabo and Mattson, 2019; Levy and Chu, 2019; Lee *et al.*, 2020). IFast involves abstaining from food for a sustained period, longer than the traditional overnight fast, with *ad libitum* food intake only permitted during a narrow eating window. IFast includes a range of approaches such as prolonged or alternate day fasting (ADF), and time-restricted eating (TRE). TRE is a daily routine with a narrow window of eating (e.g. 4 to 8 h), usually with *ad libitum* food and calorie intake in that window, and with fasting being undertaken for the remainder (e.g. 16 to 20 h) of the 24 h cycle. A form of TRE known as "16:8", i.e. 16 h of fasting with an 8 h eating window each day, is an increasingly common approach to IFast (Moro *et al.*, 2016; Gabel *et al.*, 2018; Tinsley *et al.*, 2019; Chow *et al.*, 2020; Stratton *et al.*, 2020).

To date, investigations in active adults undertaking TRE have focused primarily on changes in body composition and muscle strength during resistance exercise training (Moro *et al.*, 2016; Tinsley *et al.*, 2017, 2019; Stratton *et al.*, 2020). In trained males performing three resistance training sessions per week, 8 weeks of 16:8 TRE resulted in a decrease in fat mass compared to a control group, with no difference between groups for changes in maximal strength or muscle cross-sectional area of the upper arm and thigh (Moro *et al.*, 2016). In active females, similar improvements in skeletal muscle hypertrophy and muscular strength occurred in response to 8 weeks of supervised resistance training whether participants consumed a control diet or engaged in 16:8 TRE (Tinsley *et al.*, 2019).

To my knowledge, no randomized controlled trial has investigated the effect of a period of TRE on body composition and/or performance indices in athletic populations undertaking aerobic exercise training. However, IFast has been examined in the context of aerobic exercise training in rodents. In one study of mice subjected to 4 weeks of IFast in the form of ADF and treadmill training, an increase in endurance capacity, upregulation of molecular pathways involved in mitochondrial biogenesis, and a shift towards greater contribution of fat to energy expenditure was observed (Marosi *et al.*, 2018). If such effects were reproduced in humans, IFast may be a promising nutrition strategy to augment the adaptive response to exercise training (Levy and Chu, 2019), as demonstrated by other forms of nutrition periodization such as those that manipulate CHO availability before, during and after training (Mujika *et al.*, 2018). However, differences in the effects of different IFast regimens have been noted in pre-clinical models, as well as differences between rodents and humans in a variety of responses to fasting and IFast (Lee *et al.*, 2020). Therefore, whether effects on exercise metabolism and aerobic fitness outcomes observed in pre-clinical rodent models translate into humans is presently unknown.

The aim of the present study was to investigate the effect of 8 weeks of 16:8 TRE, when combined with habitual exercise training, on body composition, energy and macronutrient intakes, indices of endurance running performance, and markers of metabolic health in a group of trained male middle- and long-distance runners. Stated as a null hypothesis, we hypothesized that 8 weeks of 16:8 TRE would have no effect on body composition, or the abovementioned secondary outcome measures.

3 Chapter Three: Experimental chapter[5]

3.1 Methods

3.1.1 Participants

Twenty-eight trained male middle- and long-distance runners [mean (SD); age, 36.4 (7.4) y (range 20 to 49 y); height, 1.79 (0.06) m; body mass, 75.6 (9.3) kg; body fat, 12.4 (4.3) kg; $\dot{V}O_{2peak}$, 57.7 (8.5) $mL.kg^{-1}.min^{-1}$)] were recruited through local running clubs, email and word of mouth. Participants were required to be currently competing in middle- and long-distance running, considered in this study as events equal to 1500 m and above, and self-reported to be currently engaging in a minimum of five days of training per week, and to have done so for at least the previous 24 months. All participants gave written informed consent to participate after written and verbal explanations of the procedures. Ethical approval (permit number: DCUREC/2019/0029) was obtained from the Dublin City University Research Ethics Committee in accordance with the Declaration of Helsinki.

3.1.2 Experimental Design

This study employed a randomized, parallel group, PRE-POST experimental design to compare the effects of 8 weeks of TRE or habitual dietary intake (control group, CON) on body composition, energy and macronutrient intakes, indices of endurance running performance, and markers of metabolic health. The study was single blinded as the investigators involved in the analysis of the respective parameters at POST were unaware of the assigned intervention group. All participants completed a familiarization day with a battery of assessments employed and were assessed with the

[5] Published March 2021 as: Brady AJ, Langton HM, Mulligan M, Egan B. Effects of 8 wk of 16:8 Time-restricted Eating in Male Middle- and Long-Distance Runners. Med Sci Sports Exerc. 2021 53(3):633-642. doi: 10.1249/MSS.0000000000002488.

same battery of assessments at baseline (week 0; PRE), and upon completion of the intervention (week 8; POST). During each visit to the laboratory, participants completed an incremental exercise test to volitional fatigue. Fasted blood samples and measures of body composition were taken during the week of each laboratory visit. Of the n=28 participants who completed the familiarization day, n=23 participants (Table 1) met the inclusion criteria and were pair-matched (with n=1 unmatched) based on age, height, body mass and maximal oxygen uptake ($\dot{V}O_{2peak}$), with each pair then randomly assigned to TRE or CON (Figure 3. 1). Randomization was performed using sealed envelopes drawn from an opaque container that contained an equal distribution of TRE and CON envelopes. Once an envelope had been drawn, it was not returned prior to the subsequent randomization of the next pair of participants. Both groups were instructed to continue with their habitual training routine for the duration of the study. Duration of the eating window and training logs were completed daily, and semi-weighed food diaries were completed after 0 (PRE), 4 (MID), and 8 (POST) weeks of the intervention.

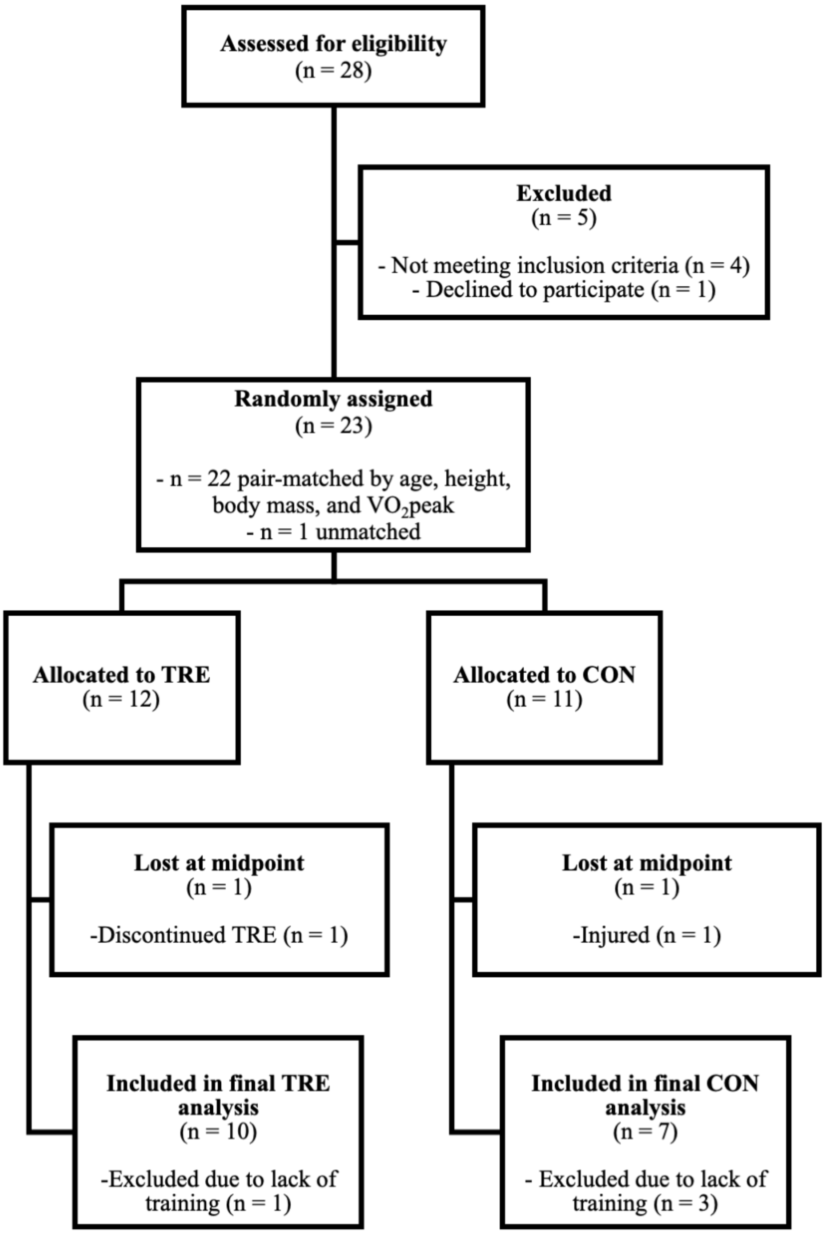

Figure 3. 1. CONSORT flow chart. $\dot{V}O_{2peak}$, maximal oxygen uptake; TRE, time-restricted eating.

The primary outcome measure was change in body mass from PRE to POST. Based on the data from Moro et al. who reported changes in fat mass in response to 16:8 TRE during resistance exercise training as decreasing from 10.90±3.51 kg to 9.28±2.47 kg from PRE to POST intervention (Moro *et al.*, 2016), the required sample size to detect a difference at a Type I error rate (α) of 0.05 and a power (1-β) of 0.8 was n=11 per group. Secondary outcomes included changes in body composition, energy and macronutrient intakes, indices of endurance running performance assessed by blood lactate concentration, running economy (RE) and $\dot{V}O_{2peak}$ in response to incremental exercise and fasting blood glucose, insulin, and triglyceride concentrations.

Table 3. 1. Participant characteristics of CON and TRE at PRE.

	CON (n = 7)	TRE (n = 10)	P value
Anthropometry			
Age (y)	39.9 (3.0)	35.9 (8.6)	0.266
Height (m)	1.81 (0.06)	1.79 (0.05)	0.542
Body mass (kg)	73.13 (6.06)	72.17 (6.68)	0.767
Fat mass (kg)	10.30 (2.67)	10.90 (4.00)	0.735
FFM (kg)	62.86 (4.92)	61.25 (3.52)	0.442
Indices of Endurance Running Performance			
$\dot{V}O_{2peak}$ (mL.kg^{-1}.min^{-1})	59.8 (5.2)	60.4 (4.9)	0.810
FBLC 2 mM (km.h^{-1})	13.8 (1.4)	14.3 (1.2)	0.412
HR at FBLC 2 mM (bpm)	158 (13)	163 (11)	0.411
%HR_{max} at FBLC 2 mM	89.7 (5.1)	88.5 (4.7)	0.622
$\dot{V}O_2$ at FBLC 2 mM (mL.kg^{-1}.min^{-1})	48.5 (3.2)	48.8 (4.5)	0.896
%$\dot{V}O_{2peak}$ at FBLC 2 mM	81.5 (6.4)	80.8 (3.2)	0.767
RE at FBLC 2 mM (mL.kg^{-1}.km^{-1})	212.5 (14.8)	204.7 (12.6)	0.263
Markers of Metabolic Health			
Glucose (mM)	4.97 (0.36)	5.22 (0.42)	0.219
Insulin (mU.L^{-1})	3.44 (0.60)	3.55 (0.73)	0.746
HOMA-IR (AU)	0.76 (0.15)	0.83 (0.22)	0.503
Triglycerides (mg.dL^{-1})	69.2 (13.7)	65.5 (20.1)	0.686

Data are presented as mean (SD). Resting blood samples were taken after an 8 h fast. CON, control group; TRE, time-restricted eating group; FBLC, fixed blood lactate concentration; FFM, fat-free mass; HR, heart rate; $\dot{V}O_2$, oxygen uptake; RE, running economy.

3.1.3 Pre-trial Preparation

All exercise testing was completed between April and September 2019. Testing was performed between 1000 h and 2000 h, but each participant completed their respective exercise tests at PRE and POST at the same time of day ±2 h in order to minimize the effect of diurnal variations on performance. Participants were asked to abstain from alcohol for 48 h prior, and caffeine for 3 h prior, to each test, and to refrain from strenuous exercise training on the day prior to each test. Participants were prescribed a standardized meal to be consumed ~2 to 3 h prior to the exercise test, which provided ~510 kcal with a macronutrient composition of 58 g CHO, 47 g protein, and 9 g fat, and was consumed with 500 mL of water. Participants wore the same running shoes for the exercise tests at PRE and POST, and were allowed to complete a self-selected stretching routine prior to being fitted with a heart rate (HR) monitor (H10; Polar, Kempele, Finland) and face mask (7450 V2 Mask; Hans Rudolph, Inc., KS, USA). The mean (SD) values for ambient temperature, relative humidity and barometric pressure were 18.6 (0.4)°C, 53.6 (6.6)%, and 763.1 (4.3) mmHg respectively at PRE, and 18.4 (0.7)°C, 54.3 (6.3)%, and 755.2 (3.6) mmHg respectively at POST.

3.1.4 Exercise Testing

All exercise tests were conducted on a motorized treadmill (T170; COSMED, Rome, Italy). The exercise test began at a speed of 9 $km.h^{-1}$ and a gradient of 1%, increasing by 1 $km.h^{-1}$ every stage until a participant reached a blood lactate concentration of ≥2 mM, a method used previously in endurance athletes to demarcate lactate threshold and facilitate comparison between athletes (Seiler and Kjerland, 2006). Each stage below 2 mM was 6-min in duration to ensure steady-state was achieved (Kuipers *et al.*, 2003), and was interspersed with a 30 s rest interval to facilitate the collection of a 15 µL capillary blood sample from the earlobe for determination of blood lactate concentrations (Lactate Pro 2; Arkray, Kyoto, Japan) (Gullstrand, Sjüdin and Svedenhag, 2007). RPE (Borg 6-20 Scale) and HR were recorded during the last 30 s of each stage. Once participants met this criterion of ≥2 mM blood lactate concentration, subsequent stages were reduced to 1 minute in duration and increased by 1 $km.h^{-1}$ every minute up to 16 $km.h^{-1}$, after which treadmill gradient was increased by 1% until volitional fatigue. Expired air was collected and analysed throughout the entire test using an automated breath-by-breath (BxB) system (Quark RMR; COSMED, Rome, Italy) which was calibrated before each test according to manufacturer recommendations. Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER) and RE were calculated from a 60 s average of BxB measurements during the last 90 s of each stage below blood lactate ≥2 mM. RE is expressed as the volume of oxygen required to run 1 km relative to body mass ($mL.kg^{-1}.km^{-1}$). The speed at a blood lactate concentration of 2 mM (FBLC 2 mM) was calculated using a polynomial equation. $\dot{V}O_2$ at FBLC 2 mM was calculated using a standard linear equation and used to calculate RE at FBLC 2 mM. $\dot{V}O_{2peak}$ was recorded as the highest 20s average observed during the test.

3.1.5 Body Composition

Stature and body composition were assessed on a separate morning during the week of each laboratory testing session, as these measurements were taken between 0630 h and 0930 h in an overnight fasted (~10-12 h) state. Participants also refrained from exercise training on the morning of these visits and were advised to consume 500 mL of water 2 h prior to the assessment. Compliance with these conditions was confirmed verbally by each participant upon arrival. After voiding of the bladder, body mass was measured to the nearest 0.1 kg using a calibrated digital scales (model 703; SECA, Hamburg, Germany), and height was measured to the nearest 0.1 cm using a portable stadiometer (model 231; SECA, Hamburg, Germany). Body composition was assessed using bioelectrical impedance analysis (BIA) (DC-430U Dual Frequency

Analyzer; Tanita, Arlington Heights, IL, USA) with fat mass and fat-free mass (FFM) generated from the analysis.

3.1.6 Blood Analysis

Fasted venous blood samples were taken by a qualified phlebotomist during the same visit as the body composition assessment. Blood was collected in plastic tubes either silicone-coated (4 mL; serum) or containing sodium heparin (2 mL; plasma) (Plus Blood Collection Tubes; Becton Dickinson, Franklin Lakes, NJ, USA) for subsequent analysis of glucose, insulin, and triglyceride concentrations. All collection tubes were pre-chilled, and blood samples were stored on ice before centrifugation at 3000g for 15 min at 4°C, after which aliquots of serum and plasma were separated for storage at −80°C until later analysis. Plasma glucose and serum triglycerides were measured using the RX Daytona™ chemical autoanalyzer and appropriate reagents as per the manufacturer’s instructions (Randox Laboratories, Crumlin, UK: assay codes GL3815 and TR3823, respectively). Serum insulin was determined by an enzyme-linked immunosorbent assay (ELISA) according to the manufacturer’s instructions (10-1113-01, Mercodia, Uppsala, Sweden). Samples for insulin analysis were run in duplicate across two plates with PRE and POST samples from the same participant analysed on the same plate. Inter and intra-plate variability were calculated using a 4-well pooled sample. Plate 1 and Plate 2 had a coefficient of variation of 5.9% and 3.4% respectively.

3.1.7 Dietary Intervention

Participants in the CON group were instructed to continue with their habitual dietary patterns for the duration of the intervention. Participants in the TRE group were instructed to consume all of their dietary intake within an 8 h window, typically between 1200 h and 2000 h. Minor adjustments to exact start or finish of this window were permitted in order to allow a meal to be consumed after the final training session each evening, or to facilitate a competitive event, but no permissions were given at any point to extend the 8 h eating window on a given day. Only water was permitted to be consumed outside of the 8 h eating window. No restrictions were placed on the frequency of meals or type of food consumed, and no dietary advice was provided other than the instruction about the 8 h eating window. Therefore, the dietary intake within the daily eating window was considered to be *ad libitum* and without caloric restrictions. All participants (both CON and TRE) were required to complete an online diary (Google Sheets) on a daily basis of the times at which they started and finished eating each day, which was frequently examined by an investigator (thereby unblinded, and not involved in the final data analyses) in order to monitor adherence to TRE. A participant's adherence with the eating window in TRE was required to be ≥80% in order to be included in the final analysis.

Prior to each laboratory visit and during week 4 (MID) of the intervention, each participant completed a four-day semi-weighed food diary. Detailed instructions on how to measure and record all food and fluid intake during this period were provided. Participants were asked to weigh each food item, or to provide a household measure equivalent, and were instructed to record each food item immediately after consumption. Food diaries were analysed using an online nutrition analysis software package (Nutritics Dietary Analysis Software; Nutritics, Dublin, Ireland) in order to calculate energy and macronutrient intake averaged over four days at each time point.

3.1.8 Training Log

Participants were instructed to continue with their habitual training routine for the duration of the intervention. None of the participants reported completing any resistance exercise training sessions during the intervention period, and with the exception of cycling training sessions spread randomly throughout both groups during the intervention period that amounted to less than ten sessions across the entire cohort, all other training sessions recorded were in the form of running sessions. Quantification of training load was performed using the session RPE method (Foster *et al.*, 2001; Stellingwerff, 2012). Briefly, training load was calculated by multiplying session duration (min) by session RPE (Borg 1-10 Scale) and is reported in arbitrary units (AU). A custom online training diary was created by the investigators (Google Sheets) and was provided to each participant to record their daily session(s) duration and session(s) RPE. Diaries were monitored daily to ensure data was being entered correctly and to monitor adherence. Participants were also required to record and provide the activity data from their GPS-enabled smart watches (Garmin; Olathe, KS, USA) to the investigators to verify training sessions were being completed. To be included in the final analysis, a participant was required to have completed a minimum of 28 sessions during the intervention period.

3.1.9 Statistical Analysis

Graphical representation of data was performed using GraphPad Prism v.8.4 (GraphPad Software Inc, San Diego, CA, USA). Data are presented as mean (SD) unless otherwise stated. Participant characteristics were compared between groups at PRE using an independent samples t-test. Univariate analysis of covariance (ANCOVA), with values at PRE for a respective outcome parameter as a covariate, was used to investigate differences between groups at POST for all primary and secondary outcome parameters, except for training parameters and dietary intake. ANCOVA and independent samples t-tests were performed using the Statistical Package for the Social Sciences (SPSS) v.25

(IBM, Chicago, IL, USA). Estimates of effect size from the ANCOVA analysis were determined using partial eta squared (η^2_p) with thresholds of ≥0.0099, ≥0.0588, and ≥0.1379 interpreted as *small*, *moderate* and *large* effects, respectively, as recommended by Cohen (Cohen, 1969) and discussed elsewhere (Richardson, 2011). A two-way (group*time) mixed analysis of variance (ANOVA) was performed in GraphPad Prism and used to determine differences in energy and macronutrient intakes (time levels: PRE, MID, POST), training load, session duration, session RPE and session count during the intervention (time levels: Weeks 1 through 8). When a main effect of group, or a group*time interaction effect was indicated, *post-hoc* testing was performed with Tukey's correction and multiplicity-adjusted P values are reported for the comparison of TRE to CON at the respective time points. Standardised effect sizes (*d*) were determined when pairwise comparisons were significantly different using the mean difference and pooled standard deviation with values interpreted as trivial when <0.2, small when ≥0.2 to <0.5, moderate when ≥0.5 to <0.8, and large when ≥0.8 (Cohen, 1969). For null hypothesis statistical testing, the significance level was set at $\alpha \leq 0.05$ for all tests.

3.2 Results

3.2.1 Participants

No difference in baseline characteristics were observed between groups (Table 1). Of the twenty-three participants who met the inclusion criteria and were randomized at PRE, seventeen (TRE, n=10; CON, n=7) were included in the final analysis (Figure 3. 1). Four participants failed to complete the minimum amount of training sessions, one participant was injured, and one participant did not respond to researchers at MID for food diary analysis. Average compliance with the 8 h eating window in TRE was 94.5 (5.1) %. The average duration of the daily eating window was 7.9 (0.2) h and 12.9 (1.0) h (P<0.001) in TRE and CON respectively.

3.2.2 Training Load

The average weekly training load reported was 1614 (410) AU and 1718 (476) AU in TRE and CON respectively. The average number of sessions completed was 42 (12) and 46 (12) for TRE and CON respectively. No main effects of group, time, or group*time interaction effects were observed for training load, session count or session RPE (Table 2). A main effect of time was observed for session duration (P=0.017), with post-hoc pairwise comparisons revealing that Week 7 was higher than Weeks 1, 2, 3 and 4 (all P<0.05, *d* = 1.12 – 1.66) in TRE. No main effect of group or interaction effect for session duration was observed (Table 2).

3.2.3 Dietary Intake

A group*time interaction effect was observed for energy intake (P=0.049) (Figure 3. 2A) with no main effects of group or time observed. The average daily energy intake in TRE decreased by 5.2 (3.6) $kcal.kg^{-1}.d^{-1}$ between PRE and MID (P=0.040, *d* = 0.65), which was equivalent to 394 (228) kcal, but despite being directionally lower by 3.2 (8.5) $kcal.kg^{-1}.d^{-1}$ between PRE and POST, which was equivalent to 265 (606) kcal, this difference was not statistically significant (P=0.413, *d* = 0.46). A main effect of group was observed for CHO intake (P=0.027) (Figure 3. 2B). CHO intake was significantly higher at PRE in TRE [4.4 (1.2) $g.kg^{-1}.d^{-1}$] compared to CON (2.7 (0.7) $g.kg^{-1}.d^{-1}$) (P=0.004, *d* = 1.73). A trend in the interaction effect for CHO intake was observed (P=0.086) with CHO intake increasing at MID and POST compared to PRE in CON, but decreasing at MID and POST compared to PRE in TRE. A trend in the interaction effect for fat was also observed (P=0.091), but no main effect of group (P=0.673) or time (P=0.608) (Figure 3. 2C). No main effect of group or time, or group*time interaction effect was observed for protein intake (Figure 3. 2D).

Table 3. 2. Overview of training sessions performed during the 8-week intervention period.

	Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	P value (time)	P value (group)	P value (interaction)
Session count (n)	CON	5.9 (0.9)	6.1 (1.3)	6.0 (1.0)	6.7 (1.3)	5.7 (1.0)	5.1 (2.7)	5.6 (2.6)	6.4 (1.9)	0.256	0.473	0.463
	TRE	6.0 (2.9)	5.9 (2.3)	5.5 (1.7)	5.3 (1.5)	5.0 (1.9)	5.1 (1.9)	5.0 (1.6)	4.9 (2.0)			
Session duration (min)	CON	64 (11)	69 (21)	62 (13)	66 (10)	68 (12)	64 (20)	72 (21)	71 (12)	0.017*	0.348	0.334
	TRE	55 (17)	58 (19)	51 (16)	58 (22)	62 (21)	62 (20)	82 (21)*	63 (16)			
Session RPE	CON	4.1 (1.3)	3.7 (1.0)	4.5 (1.8)	4.4 (1.2)	4.7 (0.7)	4.4 (0.8)	4.5 (1.4)	4.6 (1.2)	0.527	0.077	0.566
	TRE	5.1 (1.6)	5.4 (1.1)	5.4 (1.4)	5.0 (1.4)	5.6 (1.1)	5.2 (1.4)	5.1 (1.7)	5.2 (1.3)			
Training Load (AU)	CON	1661 (550)	1574 (571)	1687 (717)	1934 (497)	1790 (405)	1536 (840)	1566 (506)	2056 (650)	0.882	0.410	0.358
	TRE	1551 (686)	1700 (498)	1442 (662)	1637 (794)	1665 (1020)	1611 (744)	1852 (779)	1481 (587)			

Data are presented as mean (SD). CON, control; TRE, time-restricted eating; RPE, rating of perceived exertion. *P<0.05 vs. Weeks 1, 2, 3 and 4.

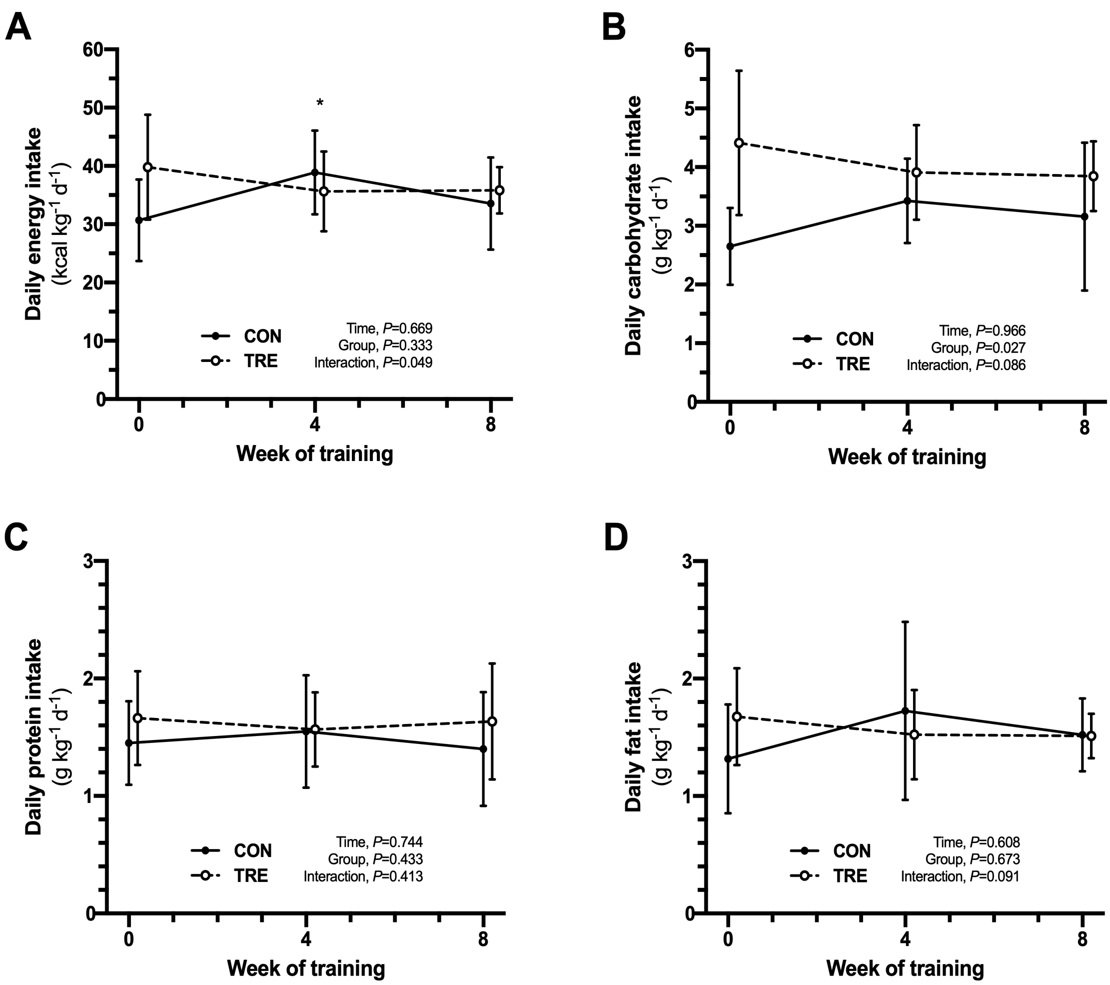

Figure 3. 2. Energy (A), CHO (B), protein (C) and fat (D) intake at PRE (week 0), MID (week 4), and POST (week 8) intervention. Data are presented as mean values with error bars representing standard deviations. *P<0.05 compared to PRE within TRE.

3.2.4 Body Composition

After adjustment for values in the respective parameters at PRE, body mass in TRE was significantly lower at POST compared to CON (mean difference of -1.92 (95% CI, -3.52 to -0.32) kg; P=0.022, η^2_p=0.321) (Figure 3. 3). Fat mass (mean difference of -0.51 (95% CI, -1.21 to 0.19) kg; P=0.139, η^2_p=0.150) and FFM (mean difference of -1.15 (95% CI, -2.46 to 0.16) kg; P=0.081, η^2_p=0.253) were not significantly different between groups.

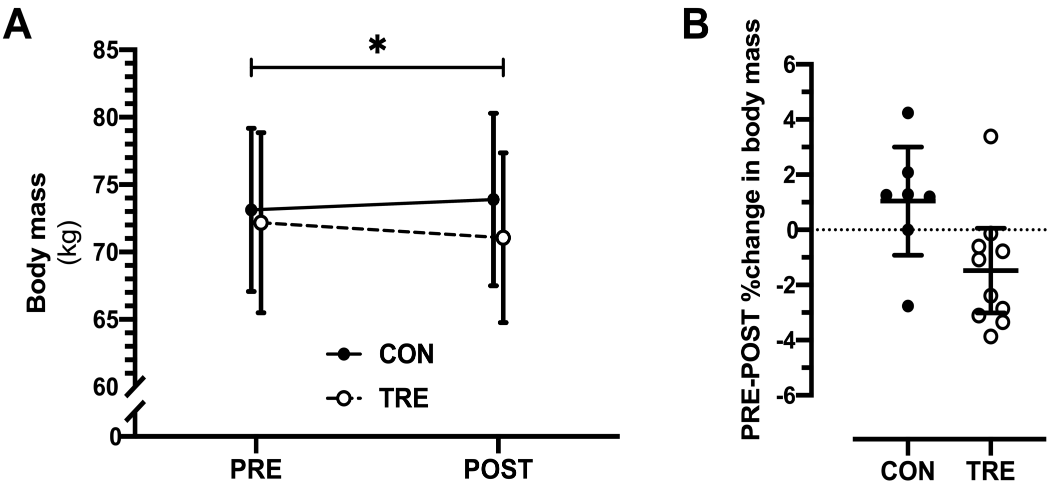

Figure 3. 3. Body mass at PRE and POST (A), and percentage change in body mass between PRE and POST (B) for each group. Data are presented as mean values with error bars representing standard deviations (A) or 95% confidence intervals (B). Circles represent individual data points from the respective groups. *P<0.05 for TRE vs. CON from ANCOVA analysis.

3.2.5 Indices of Endurance Running Performance

After adjustment for values in the respective parameters at PRE, no difference in $\dot{V}O_{2peak}$ (mean difference of -0.9 (95% CI, -2.0 to 3.8) mL.kg^{-1}.min^{-1}; P=0.505, η^2_p=0.032), FBLC 2 mM (mean difference of 0.4 (95% CI, -0.6 to 1.5) km.h^{-1}; P=0.355, η^2_p=0.061), HR at FBLC 2 mM (mean difference of 4.1 (95% CI, -2.3 to 10.6) bpm; P=0.193, η^2_p=0.118), %HR_{max} at FBLC 2 mM (mean difference of 1.5 (95% CI, -1.9 to 5.0) %;P=0.355, η^2_p=0.061), $\dot{V}O_2$ at FBLC 2 mM (mean difference of 0.6 (95% CI, -2.7 to 3.9) mL.kg^{-1}.min^{-1}; P=0.713, η^2_p=0.010), %$\dot{V}O_{2peak}$ at FBLC 2 mM (mean difference of 2.1 (95% CI, -2.5 to 6.8) %; P=0.337, η^2_p=0.066), RE at FBLC 2 mM (mean difference of -3.6 (95% CI, -10.1 to 2.8) mL.kg^{-1}.km^{-1}; P=0.245, η^2_p=0.095) were observed between TRE and CON at POST (Table 3. 3). No differences between groups were observed in relative $\dot{V}O_2$, %$\dot{V}O_{2peak}$, blood lactate concentrations, RE, RER, HR or %HR_{max} at any stage below FBLC 2 mM.

3.2.6 Markers of Metabolic Health

After adjustment for values in the respective parameters at PRE, blood analysis showed no differences between TRE and CON for fasting glucose (mean difference of 0.22 (95% CI, -0.22 to 0.65) mM; P=0.307, η^2_p=0.074), fasting insulin (mean difference of 0.32 (95% CI, -0.41 to 1.1) mU.L^{-1}; P=0.359, η^2_p=0.060) or fasting triglyceride (mean difference of 6.8 (95% CI, -38.5 to 52.1) mg.dL^{-1}; P=0.752, η^2_p=0.007) concentrations, or for HOMA-IR (mean difference of 0.11 (95% CI, -0.11 to 0.33) AU; P=0.295, η^2_p=0.078) (Table 3. 3)

Table 3. 3. Measures of anthropometry, running performance and metabolic health after an 8-week TRE intervention, with these POST data presented as unadjusted means and standard deviations and ANCOVA-adjusted means and standard error

	Unadjusted		Adjusted		
	CON	TRE	CON	TRE	P value
Anthropometry					
Body mass (kg)	73.90 (6.40)	71.06 (6.29)	73.36 (0.57)	71.44 (0.48)	0.022*
Fat mass (kg)	10.24 (2.52)	10.23(3.30)	10.54 (0.25)	10.02 (0.21)	0.139
FFM (kg)	63.64 (5.50)	60.81 (3.65)	62.65 (0.47)	61.50 (0.39)	0.081
Indices of Endurance Running Performance					
$\dot{V}O_{2peak}$ (mL.kg^{-1}.min^{-1})$^-$	59.6 (5.6)	59.2 (4.6)	59.9 (1.0)	59.0 (0.9)	0.505
FBLC 2 mM (km.h^{-1})	13.4 (1.6)	14.2 (0.9)	13.6 (0.4)	14.0 (0.3)	0.355
HR at FBLC 2 mM (bpm)	153 (17)	162 (11)	156 (2)	160 (2)	0.193
%HR_{max} at FBLC 2 mM	87.2 (4.9)	88.0 (3.7)	86.8 (1.2)	88.3 (1.0)	0.355
$\dot{V}O_2$ at FBLC 2 mM (mL.kg^{-1}.min^{-1})	47.1 (4.9)	47.9 (3.2)	47.2 (1.2)	47.8 (1.0)	0.713
%$\dot{V}O_{2peak}$ at FBLC 2 mM	79.3 (7.1)	81.0 (3.3)	79.0 (1.6)	81.1 (1.4)	0.337
RE at FBLC 2 mM (mL.kg^{-1}.km^{-1})	212.0 (12.3)	203.0 (9.9)	208.8 (2.3)	205.2 (1.9)	0.245
Markers of Metabolic Health					
Glucose (mM)	5.00 (0.35)	5.26 (0.41)	5.03 (0.15)	5.24 (0.13)	0.307
Insulin (mU.L^{-1})	3.10 (0.49)	3.45 (0.78)	3.11 (0.26)	3.44 (0.22)	0.359
HOMA-IR (AU)	0.69 (0.14)	0.81 (0.23)	0.70 (0.08)	0.81 (0.07)	0.295
Triglycerides (mg.dL^{-1})	76.1 (37.3)	79.7 (48.1)	74.2 (16.1)	81.0 (13.5)	0.752

Resting blood samples were taken after an 8 h fast. CON, control; TRE, time restricted eating; FBLC, fixed blood lactate concentration; FFM, fat-free mass; HR, heart rate; $\dot{V}O_2$, oxygen consumption; RE, running economy. *P < 0.05 based on outcome of ANCOVA analysis of adjusted means.

3.3 Discussion

The present study investigated the effect of 8 weeks of 16:8 TRE, combined with self-selected habitual training, on body composition, energy and macronutrient intakes, indices of endurance running performance, and markers of metabolic health. Compared with habitual dietary intake and exercise training, TRE resulted in a reduction in body mass commensurate with a reduction in energy intake. TRE did not impact exercise training or indices of endurance running performance, nor were any effects on blood markers of metabolic health observed.

IFast is of growing interest in athletic populations (Levy and Chu, 2019), a fact that may be attributable to proposed benefits in fuel utilization and body composition observed in rodents undertaking IFast combined with exercise training (Marosi *et al.*, 2018; Real-Hohn *et al.*, 2018). While there is an increasing body of evidence demonstrating beneficial effects of IFast and aerobic exercise training on blood lipids and other cardiometabolic health markers in overweight and obese populations (Bhutani *et al.*, 2013; de Cabo and Mattson, 2019), the present study is the first to investigate the effect of a period of IFast in the form of 16:8 TRE in an endurance-trained population. Previous studies of TRE in athletic populations have focused primarily on resistance training with mixed effects reported. Trained females who engaged in 8 weeks of 16:8 TRE with resistance training demonstrated minor increases in energy intake, but similar gains in FFM and an overall reduction in fat mass compared to a control diet (Tinsley *et al.*, 2019). In resistance trained males, after 8 weeks of 16:8 TRE energy intake was unchanged, but body mass [-0.40 (1.76) kg] and fat mass [-0.96 (1.72) kg] were reduced (Moro *et al.*, 2016). In contrast, self-reported energy intake was reduced by ~650 kcal on non-training days (four days per week) in young recreationally trained males who utilized an *ad libitum* 4-h eating window (20:4 TRE) compared to unrestricted eating on training days (Tinsley *et al.*, 2017). However, despite this reduction in calories on non-training days, body composition was unchanged after 8 weeks of intervention (Tinsley *et al.*, 2017). Athletes with a better understanding of nutrition requirements for their mode of exercise make better nutrition decisions (Holtzman and Ackerman, 2019), therefore counselling participants in such studies may alter eating behaviour, and be a confounder when aiming to isolate the effects of TRE as an intervention. Moreover, the use of nutrition supplements (Tinsley *et al.*, 2019) and standardized diets (Moro *et al.*, 2016, p. 201), including intentional calorie restriction (Stratton *et al.*, 2020), make it difficult to assess the true extent of IFast on energy intake and body composition in the exercising adults studied to date.

In the present study, no dietary advice other than explanation of the eating window to the TRE group was provided. No restrictions were made on meal frequency or timings with participants simply directed to eat *ad libitum*, be that in terms of calories or types of food, during their respective eating windows. TRE resulted in a reduction in self-reported energy intake of 394 (228) kcal per day by MID, but despite being directionally lower at POST by 265 (606) kcal per day, this difference was not statistically significant due to large inter-individual variation. The pattern of reduced energy intake on TRE days after 4 weeks, but returning towards PRE intervention values after 8 weeks was a pattern that was apparent in a previous study of active males engaged in TRE while undertaking resistance training (Tinsley *et al.*, 2017). Longer term studies of TRE will be required to investigate whether changes observed after 4 to 8 weeks are sustained during longer duration adherence to TRE, or whether compensatory behaviours consistently emerge that result in daily energy intakes that are similar to habitual, pre-

TRE intakes. That said, in the present study these declines in energy intake were largely explained by downward trends in CHO intake over the 8-week period, and fat intake in the first 4 weeks of the intervention. Coincident with the decrease in energy intake in TRE, a reduction in body mass of ~1.5% (or ~1.1 kg) was observed from PRE to POST. This loss of body mass cannot definitively be attributed to the effect of TRE on energy intake, given that energy expenditure was not measured as part of the energy balance equation. However, exercise training load was unchanged throughout the 8-week period, and participants were asked to maintain all other daily activity habits as normal. While overall body mass was reduced in TRE, examination of the individual components of fat mass and FFM showed both were directionally lower, with FFM trending towards the threshold of 0.05 chosen for statistical significance. The small sample size of participants completing the intervention in the present study cannot be ignored in this light, and likely resulted in this analysis being underpowered for null hypothesis statistical testing. However, effect sizes for decline in body mass (η^2_p=0.321), fat mass (η^2_p=0.150), and FFM (η^2_p=0.253) are all interpreted as *large* effects.

This downward trend in FFM with TRE was observed despite protein intake ranging from 1.4 to 1.7 $g.kg^{-1}.d^{-1}$ at all timepoints for both groups, in line with the recommended daily intake for endurance athletes (Witard, Garthe and Phillips, 2019). Alternatively, the decline in daily CHO intake in TRE may have negatively impacted body glycogen stores, which in turn could have reduced total body water given the association of each gram of glycogen with ~3 g of water (Bergström and Hultman, 1972). This change in total body water would have the effect of both reducing overall body mass but also resulting in a lower quantity of FFM when measured by BIA (Kyle *et al.*, 2004). Of course, the use of self-reported food diaries to monitor dietary intake are not without limitation.

Issues of underreporting and altered behaviour are common, and thus the results from these records should be interpreted accordingly (Burke *et al.*, 2018). However, measurement of body composition by BIA is not without limitation since BIA is known to under- or overestimate fat mass and FFM compared with dual-energy X-ray absorptiometry (DXA) (Achamrah *et al.*, 2018). That said, foot-to-foot bioelectrical impedance analysers similar to that used in the present study demonstrate good reliability for the assessment of body composition in active males, with between-day coefficients of variation (CV) of ~2.0-2.5% reported (Swartz *et al.*, 2002; Dixon *et al.*, 2006). In the present study, the reduction in fat mass in TRE was ~0.67 kg, equivalent to a relative reduction of ~6.2%. In contrast, the reduction in FFM in TRE was only 0.7%. Therefore, changes in FFM lie within the typical error of measurement for BIA and should be interpreted with caution, but the 6.2% reduction in fat mass is likely to be the major component of the observed reduction in body mass. Therefore, with these data and caveats all considered, we contend that 8 weeks of 16:8 TRE resulted in practically-meaningful changes in body mass and composition, in addition to energy and macronutrient intakes, which warrant further investigation in future studies.

An important finding of the present study is that this period of TRE did not impact a variety of parameters employed to monitor exercise training. No differences were observed between groups for training load, duration, intensity, or frequency throughout the study. While there were inter- and intra-individual variations in the weekly training load, this is reflective of modern training programmes, which alternate between periods of increasing volume and intensity with periods of recovery (Stellingwerff, 2012). The participants were also directed to continue with their self-selected habitual training routine for the duration of the intervention period. Given the different types of training periodization used by endurance athletes (Mujika *et al.*, 2018), these variations in training load are not unusual. While the reduction in energy intake did not result in a decline in training performance, it is important to note that the training loads reported in the present study are considerably lower than those of elite endurance athletes (1,614 *versus* ~3,350 AU) (Stellingwerff, 2012). Higher training loads require a greater energy intake, with particular reliance on CHO for high-intensity and prolonged aerobic exercise (Hawley and Leckey, 2015). The aforementioned changes in self-reported dietary intake in TRE led to a 14% and 11% reduction in CHO intake at MID and POST respectively. Manipulation of CHO intake is a common nutritional strategy amongst endurance athletes with the aim of improving metabolic flexibility and augmenting mitochondrial biogenesis, but requires careful planning and consideration of the energy requirements for exercise training (Burke *et al.*, 2018). The observed decline in energy and CHO intake appears to be spontaneous in nature rather than a conscious or intentional reduction, and therefore if prolonged, may lead to a state of low energy availability (LEA) in the absence of a decline in training load. Persistent LEA can lead to a variety of health and performance decrements, such as impairing muscle protein synthesis and blunting the adaptive response to training, and increasing the risk of injury and illness (Mountjoy *et al.*, 2018). In this regard, future investigations should examine the long-term effects of TRE in more elite endurance athlete populations, especially those with greater training loads.

Blood lactate concentrations, RER and RE (oxygen cost of running at a given velocity) at incremental running speeds were used in the present study as indicators of improved endurance running performance and substrate utilization during submaximal exercise. Along with $\dot{V}O_{2max}$, lactate concentrations and RE are the best indicators of training adaptation and running performance in endurance athletes (Midgley, McNaughton and Jones, 2007; Joyner and Coyle, 2008). The lack of change in these metrics may be a consequence of an inadequate training stimulus due to the aforementioned unstructured training because significant improvements in these metrics have been observed in trained participants during short-term training programmes (Jones and Carter, 2000). However, we deliberately chose not to include a structured exercise training intervention in the present study as our aim, *a priori*, was to examine the effects of TRE itself, rather than TRE combined with a progressive overload, on aerobic fitness and indices of endurance running performance. In contrast, when IFast in the form of ADF was combined with intensive exercise training in mice, endurance running capacity was improved, in addition to a range of metabolic changes (Marosi *et al.*, 2018). For example, trained ADF mice demonstrated reductions in RER with elevated concentrations of ketone bodies, indicative of a shift in the contribution to energy provision from substrate utilization of CHO to fat, and an improvement in metabolic flexibility. The expression of peroxisome proliferator-activated receptor alpha (PPARα), an important regulator of genes involved in fatty acid uptake, was increased along with the increased expression of pyruvate dehydrogenase kinase 4 (PDK4), an inhibitor of the pyruvate dehydrogenase kinase complex, thereby potentially contributing to the reduction in glycolytic flux (Marosi *et al.*, 2018). Reductions in RER, indicative of a reduction in the reliance on CHO to energy provision, do not always translate into improvements in exercise performance (Burke and Hawley, 2002; Hawley and Leckey, 2015). The increased availability and oxidation of free fatty acids, which is a consequence associated with fasting and low CHO ketogenic diets, is now recognized as having an inhibitory effect on glycolytic flux, rather than a "glycogen sparing" effect as previously hypothesized (Hawley and Leckey, 2015). However, in contrast to the results observed in mice undertaking ADF and exercise training, results of the present study do not support these findings, with no changes in RER or RE at any submaximal intensity, and no change in lactate concentrations observed. Lastly, no changes in fasting glucose, insulin or triglyceride concentrations were observed. These findings are in contrast to a previous report in resistance trained males undertaking 16:8 TRE for 8 weeks that observed reductions in glucose, insulin and triglyceride concentrations in the TRE group (Moro *et al.*, 2016). The reason for this discrepancy between the studies warrants further investigation, especially given the often-stated cardiometabolic benefits of IFast (de Cabo and Mattson, 2019). Likely explanations are the greater level of aerobic fitness at baseline in the present study, and persistent high level of aerobic exercise training throughout the intervention, meaning that the range for improvements in markers of metabolic health by TRE was relatively narrow.

There are a number of limitations to be considered in the present study. Firstly, sample sizes of ten and seven participants in the TRE and CON group respectively is underpowered relative to the *a priori* sample size (n=11 per group) required. Several notable trends were observed in relation to change in body composition and dietary intakes, but these will require larger sample sizes in future studies in order to confirm these findings. The present study was designed to investigate the effect of TRE when undertaken in conjunction with self-selected habitual exercise training, and therefore the results cannot be extrapolated to predict how TRE would interact with the adaptive response to a structured exercise training programme designed to improve endurance running performance. While this experimental approach was used to improve the ecological validity of the study, it resulted in four (n=1 TRE; n=3 CON) participants being excluded in the POST analysis for a lack of sufficient training, which also contributed to the small n-sizes per group. In addition to providing a structured exercise training programme, it would be worthwhile to investigate whether the time of training, and therefore whether training sessions are performed in the fasted or fed state of TRE, would impact the adaptive response under this approach. Finally, the indices of endurance running performance and substrate utilization may not be sensitive enough to detect changes at a whole-body level with just 8 weeks of intervention. At a molecular level, changes have been observed in previous work in rodents in shorter time frames (Marosi *et al.*, 2018; Real-Hohn *et al.*, 2018), and given the differences between rodents and humans in the response to IFast (Lee *et al.*, 2020), it may be that a longer duration of intervention would be needed to observe changes at a whole body level in humans. Future studies involving tissue samples would be needed to fully elucidate changes, if any, at a molecular level in human skeletal muscle in response to TRE.

In summary, 8 weeks of 16:8 TRE in trained middle- and long-distance runners resulted in a spontaneous reduction in self-reported energy intake and a reduction in body mass, but did not impair exercise training or alter indices of endurance running performance. The reduction in body mass was comprised of directional reductions in both fat mass and FFM being *large* effect sizes, albeit not reaching the threshold for statistical significance, and in the case of FFM may be confounded by the limitations of the assessment of body composition by BIA. These preliminary observations will therefore require further investigation in future studies. The spontaneous reduction in energy intake represents a potential alternative to alter body composition with *ad libitum* food intake within a narrowed eating window, rather than intentional caloric restriction. However, the reductions in CHO intake and FFM as a consequence of TRE require further investigation to explore whether this dietary intervention produces adverse long-term effects on energy availability or training adaptations. In this regard, future work should investigate the effect of TRE using a structured exercise programme over a prolonged period and examine the impact of TRE in an elite population with greater training loads.

4 Chapter Four: Exit survey and findings

4.1 Background

Upon this completion of the intervention study of Chapter 3, subjective experiences of the participants were captured by a bespoke exit survey administered via Google Forms (Appendix c). This type of qualitative analysis to compliment traditional quantitative analysis is attaining greater interest and increasingly use despite not typically being associated with laboratory-based research. As an illustrative example, a recent study by (Parr, Devlin, Lim, *et al.*, 2020) investigated TRE as a nutrition strategy in patients with type 2 diabetes and complimented the primary metabolic outcomes by using additional qualitative and quantitative methods for the analyses of psychological wellbeing and cognitive functioning (Parr, Devlin, Lim, *et al.*, 2020). The Cogstate Brief Battery (CBB) was used to measure a number of cognitive brain functions in patients and was followed with qualitative analysis of semi-structured interviews to interpret the participants' perspective and progress during a four-week intervention.

4.2 Rationale for the experimental approach

Qualitative surveys are typically associated with social sciences research, and therefore the potential for surveys (online or printed) to compliment quantitative data through qualitative data collection or analysis is not always recognised (Braun, Clarke and Gray, 2017; Terry and Braun, 2017). Similarly, fully quantitative surveys are insufficient for qualitative data collection, but the use of surveys with open-ended questions and free text boxes are proposed to have potential to enhance outcomes alongside other quantitative data, especially in mixed methods approaches (Braun *et al.*, 2020). Specifically, qualitative surveys can be more relatable to psychosocial issues or can seek more nuanced interpretations of a series of questions that may not be anticipated by other data collection methods, especially when participants are asked to give their own feedback rather that pre-determined responses, thus acquiring more impartial results (Braun and Clarke, 2013). Participants' subjective experiences, practices and discourses, determined in their responses, can account for more complexity and of greater value to qualitative researchers (Braun and Clarke, 2013). In mixed methods research, this allows the researcher to acquire feedback or findings that quantitative methods may not analyse. Whilst strictly speaking this study cannot be categorised as mixed methods research, it incorporates an element of qualitative data to further enhance the quantitative data outlined in Chapter 3.

Thematic analysis is a method of analysing qualitative data to achieve purposeful understanding of participant perspectives, by identifying patterns within such data, and allowing researchers to advance these data into meaningful categories (Braun & Clarke, 2006). Therefore, thematic analysis is a valid strategy for mapping out content from data collected in open-ended questions, and therefore has recently been described in the context of the analysis of qualitative surveys (Braun *et al.*, 2020). This framework is built upon the seminal work on the methodology for thematic analysis by the same authors from the mid-2000s (Braun & Clarke, 2006), which itself has been complimented by more recent work describing the organisation of data into themes to provide meaningful outcomes (Creswell, 2012; Sutton and Austin, 2015). Surveys that use closed- or open-ended questions, or a combination of both may use thematic analysis alongside a numerical rating scale for collecting mixed methods data (Ponto, 2015). However, surveys with greater use of open-ended questions can give the participant the opportunity to express their mindset and use their own language in their response. Additionally, in using their own language, participants may demonstrate a greater ability to communicate their critical thinking (Swart, 2019).

Therefore in this study an evaluation survey was presented at the end of the intervention period to further assess participant's feedback of their interaction and participation. The survey was developed based on the inquiry logic and interview questions described in previous studies on the same theme of the barriers, facilitators and experience of undertaking TRE (Parr, Devlin, Lim, *et al.*, 2020; Parr, Devlin, Radford, *et al.*, 2020). These questions were designed to gain insight into the attitudes and opinions, potential barriers, likelihood of adhering to a TRE dietary approach long term, and influence of TRE on hunger i.e. these previous studies were in overweight and obese men (Parr, Devlin, Radford, *et al.*, 2020) and type 2 diabetic men and women (Parr, Devlin, Lim, *et al.*, 2020). Therefore the present study retained much of the same focus as these previous studies in terms of barriers, facilitators and experience of undertaking TRE, but notably differed by replacing questions around hunger with questions pertaining to the influence of adherence to TRE on performance. These modified questions were reviewed by three expert sports nutritionists who provided verbal feedback on the language and relevance of the questionnaire items. This feedback included the recommendation to ask separate questions about performance by including questions specifically focussed on performance in the laboratory testing, and performance in competitive races. After implementing these changes, the questionnaire was piloted on three male endurance athletes known to the research team but whom did not participate in the study, who also provided verbal feedback on the language and relevance of the questionnaire items. A further suggestion for change to the pilot questionnaire arising from this feedback was the inclusion of a question on the perceived influence of adherence to TRE on performance in training as distinct to laboratory testing and races. The final survey comprised of nine questions, of which four questions were open-ended questions annexed with space for further comment. The questions were arranged to survey the impacts of TRE on diet, training, performance and on the laboratory-based tests of aerobic fitness and indices of endurance performance. The survey was brought to close with an observation on any other challenges that may have occurred during the study. Survey is included as Appendix b.

4.3 Present study findings

A thematic analysis of the survey responses was carried out using NVivo Qualitative Data Analysis (QDA) software to ascertain meaningful results from these responses. The data were analysed and a hierarchy of themes was generated as shown in Figure 4. 1 outlining both the higher-order themes and sub-themes. The entire dataset is added as reference (Appendix c). The four higher-order themes included the expected themes of (A) Barriers, and (B) Facilitators, but also included emergent, and contradictory, themes in the form of (C) Benefits, and (D) Decreased Training and Competitive Performance.

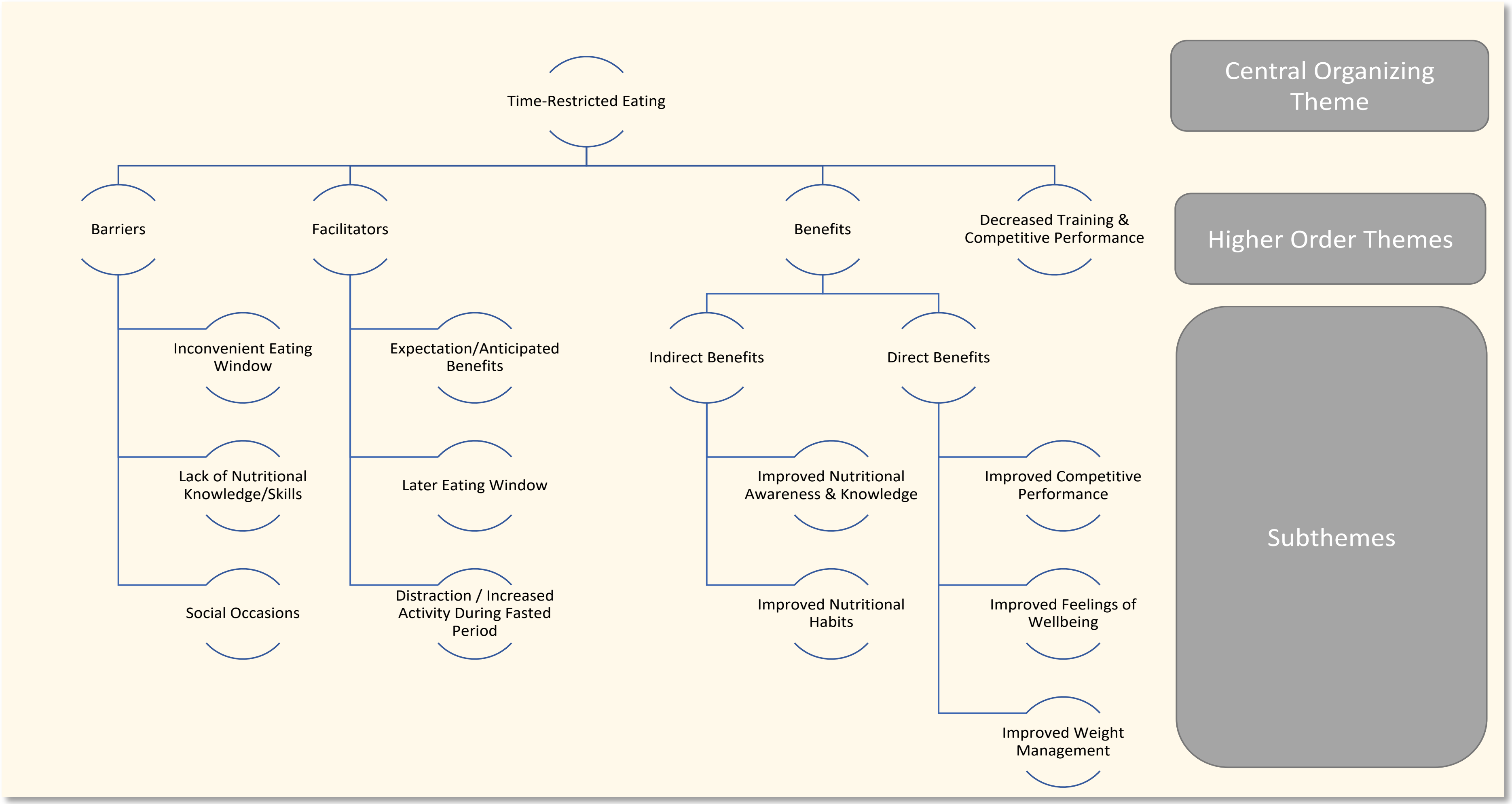

Figure 4. 1 Thematic analysis of exit survey using NVivo Qualitative Data Analysis (QDA) software. Diagram displays hierarchy of themes and overall findings of survey responses.

A. Barriers

Participants were specifically asked to report on challenges that may have arisen implementing the TRE approach, whereas other mention of barriers emerged in the question about continuing with TRE in the future. The sub-themes identified within the barriers theme included the inconvenience of the eating window, the challenge of social occasions, and the lack of nutrition knowledge/skills.

As per the study design and instructions provided to participants, the eating window was flexible in terms of when it took place on any given day, as long as it was 8 hours in duration. However, participants still reported the timing of the eating window being a challenge, with challenges being noted whether participants engaged in an early eating window, where evening eating/snacking was a challenge.

> *TRE004 "Evening time snacking somewhat difficult to cut out. Missed coffee in the morning." too."*
>
> *TRE011 "Tough to cut out the evening eating."*
>
> *TRE016 "I found myself feeling sluggish during training sessions in the evening time, from consuming so much food in a relatively short space of time earlier in the day."*

Or whether participants engaged in a late eating window, where the abstinence from caffeine/coffee was noted as a challenge.

> *TRE005 "Hard initially to get into a routine and to trust that you wouldn't starve to death!! Lack of caffeine was very tough. After 3 weeks found it pretty easy other than the lack of morning coffee. Still doing it today although not as strictly."*
>
> *TRE015 "No Caffeine was probably the most difficult part."*

Regardless choosing an early or late eating window, social occasions that took place within the fasting window were challenging for participants.

> *TRE028 "Meeting people prior to or after the window and drinking a class of water rather than tea/coffee."*

As a result, it was apparent that adherence to TRE required a certain degree of forward planning in order to implement the strategy successfully, especially as that relates to the planning of food around training times.

> TRE016 *"Not having breakfast first thing when you wake up. Planning mealtimes on training days."*
>
> TRE019 *"Most difficult part was planning your training so that the training was done in the 8-hour window period for eating so most of the time that meant not eating until 1:30pm each working day for me."*

The recognition of the important of meal planning around training is unsurprising given that fuelling appropriately for training sessions, and recovering adequately are well-recognised cornerstones of sports nutrition practice (Burke and Hawley, 2018). However, one challenge was the knowledge and skills needed to support good sports nutrition practice, although it must be said that this challenge may not necessarily be specific to TRE.

> TRE017 *"Balancing work/life commitments with fuelling/refuelling for training/races into the eating window was difficult. Similarly, on busy work/life days, it could be difficult to eat daily calorie allocation."*
>
> TRE001 *"Focus on eating correct food"*

The recognition of the important of meal planning around training is unsurprising given that fuelling appropriately for training sessions, and recovering adequately are well-recognised cornerstones of sports nutrition practice (Burke and Hawley, 2018). However, one challenge was the knowledge and skills needed to support good sports nutrition practice, although this may not necessarily be specific to TRE.

B. Facilitators

While adherence to the eating windows throughout the intervention was high, few facilitators were noted as specific strategies, yet the implementation of a structure and better food choices emerged as facilitators/motivators.

TRE011 "Gave a structure to my eating and concentrated my focus."

TRE015 "I found it gave me structure and allowed me focus on my eating habits.

TRE016 "The need for snacking was cut down to a minimum. Overall, eating habits were better."

TRE011 "Once back in work it became easier as it gave a structure to your day. Weekend was tougher as the temptation of food was always around."

TRE005 "Got out the door in the morning a lot quicker without breakfast. Planning and preparing food the night before was key for me."

Participants also reported that a period of transition or adjustment was required until they became "used to" the approach.

TRE003 "Difficult at the start, had some slight headaches in the morning coming up to lunch time. After a week or two I adjusted to it and am doing it since although not as rigorously as before."

TRE019 "Otherwise, your body gets used to it after a week of same."

The expectation/anticipation of benefits, and the perception of benefits were also stated as facilitators of adherence to TRE.

TRE017 "Felt leaner. Eat fewer sweet foods. Possibly related! Energy levels throughout the day felt more balanced."

TRE011 "Felt better within myself. Lost weight and the eating plan felt like it put a positive focus on your day-to-day life. Had more energy."

TRE001 "Healthier choice eating, slightly leaner."

C. Benefits

Many benefits of TRE were reported by the participants, which were categorised in to indirect and direct benefits as they pertain to performance in laboratory testing, training, and races. Indirect benefits were categorised as those which were positive in nature but did not necessarily make reference to performance, and therefore largely related to health and wellbeing. These included improved nutrition awareness and habits, and perceived effects on metabolism and body composition.

TRE019 "I felt like I was not craving food as much and I also saved time in mornings not eating breakfast going to work!

TRE016 "The need for snacking was cut down to a minimum. Overall, eating habits were better."

TRE004 "I felt I digested my food better and wasn't as bloated or full feeling as I often am in the morning and throughout the day."

TRE001 "Healthier choice eating, slightly leaner."

Indeed, the effect on body mass and/or body composition was noted by several participants as a benefit of the TRE intervention.

TRE005 "Half a stone weight loss and I've maintained it. Even after summer hols didn't put the weight back on which is unusual for me."

TRE005 "Lost weight. Felt good. Confident in running on empty."

Several direct benefits on performance were reported by participants, although as outlined in the results in Chapter 3, these were not evident as between-group differences in the laboratory-based tests of indices of performance. Unintentional improvements in diet and food intake during the intervention could account for some of these perceived benefits. Even with those caveats stated, reported benefits were evident for each of the domains i.e., laboratory testing, training, and races.

TRE019 "I felt fitter, and my test result seemed to improve over the months. My lactate threshold I think improved."

TRE011 "Increased interest in training coupled with weight loss led to better race times."

TRE003 "The time I could sustain a run for without eating went from around 1:30h - 2h."

TRE005 "PB's in 3 consecutive 5ks, poor race in 10 miler, but big PB's in half and full marathon."

TRE003 "Marathon time came down 30 mins from the previous year."

TRE019 "I felt stronger towards end of races in that lactate was not building up as quickly in my legs as before."

D. Decreased Training and Competitive performance

Yet despite these several positive reflections, there were also negative reflections on decline in training and competitive performance. These negative outcomes being in contrast to the positive reflections suggests that there is a heterogenous response at an individual level to a TRE intervention.

> TRE017 *"I believe this year I ran more miles that the same period last year, and yet my race times degraded." … "Race times were slower; Dunshaughlin 10k is a good example - approx. 2 mins slower between this year and last year."*
>
> TRE028 *"Restricted eating is not conducive to early morning races."*

The negative impact on performance in competitive races may have been due to a reduced quality of training caused by issues including energy levels and recovery.

> TRE016 *"I found myself feeling sluggish during training sessions in the evening time, from consuming so much food in a relatively short space of time earlier in the day."*
>
> TRE028 *"Speed work was negative, longer slower training runs had little effect. Just have food ready on return. I was fortunate to be flexible with my training times.*
>
> TRE017 *"General performance in training was slower."*

4.4 Discussion

The thematic analysis of the survey provides a structure to the interpretation of the participant response on their experience of the TRE intervention. Evaluations or questionnaires as employed herein can be designed to find any difficulties or opportunities that participants may have experienced over a study timeline, intervention, or participation. These are evidential in the above higher-order themes of "Barriers" and "Facilitators" respectively and further highlighting the sub-themes that were raised amongst participants. Interestingly, "Indirect benefits" theme showed that a majority of participants reported improvements in nutrition awareness and dietary habits. In the higher order theme "Perceived direct benefits", participants expected to see improvements in training, weight management and digestion/wellness. The nature of the survey did not allow for exploration of where these expectations were derived, but the exception of weight management, the evidence base in the published literature is scant, especially for athletes. Furthermore, in the “perceived negative impact” theme, a number of participants reported a decrease in training and competition day performance, thus negating the expected benefits of improved performance in the previous theme.

Therefore, as a participant experience, responses to training and performance were dichotomous: a number of participants reported improvements in performance including personal bests and improved marathon times, whereas other participants observed their race time to be slower compared to previous years. An interesting observation is that for several individuals a number of the indices of endurance performance measured in the lab-based fitness tests improved in parallel with their perceived improvements in training quality. This effect may be explained with the intention to improve performance over the progression of the intervention period, but not necessarily a consequence of TRE. i.e., a main effect of time but no significant interaction effect. For those individuals reporting a deterioration in training and performance during TRE, this might be explained, in part, by reduced calorie intake due to extended fasting periods each day and shorter eating windows. This observation correlates with the overall results observed for calorie intake and body mass in the TRE group over the intervention period, but ultimately at a group level TRE did not impact exercise training or indices of endurance running performance over the same time-period.

The findings where declines in performance were perceived are therefore particularly notable for being contradictory to the absence of effect of TRE on outcomes of the lab-based assessment of running performance. As such, these qualitative data are arguably illustrative of the value of this type of experimental approach in that these are accounts of participants' own experiences of the intervention that cannot be (or were not) observed by quantitative results. Paradoxically, one must then consider which is the more important outcome – that the lab-based measures were unaffected, or that some participants perceived their performance as negatively impacted. Quantitative data may be fundamental to assessing the efficacy and effectiveness of exercise and nutrition interventions, but this can be further enhanced with appropriate evaluation of the participants' experience of the same. For this reason, qualitative data collection can be an effective approach beyond tools such as ergometers and food diaries for the evaluation of interventions.

Notably, the main findings of the qualitative interviews in the abovementioned Parr et al. (2020) study that are echoed by this thesis is that participants reported difficulties managing times outside the eating window, with examples such as where they felt "hunger" and "missing morning coffee". A number of participants informed that the void of morning coffee and lack of caffeine in the morning period was a challenge. In addition, missing out on early breakfast, difficulty of planning meals around training, and abstaining from evening meals proved socially challenging i.e., trying to integrate their eating times with family, social and work commitments. Given the contrasting study populations between Parr et al. (2020) and the present work (Australian middle-aged type 2 diabetic patients vs. Irish adult endurance athletes), yet similar experiences of TRE, this is likely to be a common experience of those implementing IFast in the form of 16:8 TRE, and there are some common habits and social conventions with which food consumption is associated.

In addition, some participants were negatively impacted by hunger, eating behaviour and food choices while other participants were able to withhold satiety, thereby reflecting rather different experiences within the cohort. A similar dichotomy was noted for food quality whereby certain participants were able to plan healthier meals, whilst other opted for convenient food due to an absence of diet planning. Lastly, adjustments to late night snacking were a contentious issue for participants, but this would be anticipated given that in society working arrangements have evolved to shift work and extended evening hours, and many social occasions take place in the evening time (Hemmer *et al.*, 2021).

Another important observation by Parr et al. (2020) is that TRE evokes agreeable and disagreeable responses, where some participants adhere well to the IFast protocol and others are overwhelmed physically and emotionally with the adjustments made to their diet. Anticipating these adjustments for some participants may lead to stress and anxiety and may negatively influence the outcomes of an IFast study. This is an important counterpoint to the assertion often made that IFast is an easier approach to dietary intervention because it does change what a person eats, only the time at which they eat. However, other elements of TRE show positive outcomes, whereby participants find the structured and monitored approach to diet to be beneficial and therefore show better adherence to the intervention. A conclusion on this approach is to deliver well-structured and clear direction in the protocol framework followed by accessible communication thereafter (Parr, Devlin, Lim, *et al.*, 2020).

A final observation from the questionnaire data is that when participants were asked if they "*notice any other changes in your body or general life as a consequence of the time-restricted eating approach*", the extent of the responses showed positive conclusions in their findings. Responses included "felt leaner", "had more energy", "digestion functioned better", "overall, eating habits were better" amongst others.

These perceived benefits echo the types of anecdotal claims for IFast protocols that are evident in some of the popular blogs and books mentioned in Chapter 1. As stated earlier, these claims are largely unsubstantiated in the peer-reviewed literature, and while these responses lend some empirical support to these claims, a more rigorous approach to exploration of these claims/experiences in greater depth such as through semi-structured interviews would be valuable in future research. In addition, these differences in individual experiences of TRE speak to the value of future studies with larger sample sizes in which investigation of inter-individual differences are thoroughly undertaken.

5 Chapter Five: Contemporary findings and future directions

5.1 Up-to-date contemporary findings

Since this thesis was published as a peer-reviewed paper in August 2020 (online ahead of print), two other notable papers have been published. The first was a paper by Moro et al. (2020) published shortly after my work, and also claimed to be the first study to investigate IFast in endurance athletes (Moro *et al.*, 2020). This group of researchers have been prolific in the study of TRE in active adults and athletes, albeit with resistance exercise training, and their work forms the bulk of the section on TRE in human participants in the Literature Review in Chapter 2 and Table 2.1.

In this most recent study, Moro et al. (2020) conducted a 4-week randomised controlled trial to investigate the effects of TRE in the form of 16:8 on performance, immune function, and body composition in elite cyclists. Sixteen U23 male elite cyclists were randomly assigned to a TRE or control group consuming normal diet (ND). The TRE group consumed 100% of its prescribed calorie intake in an 8 h window, but notably this was over four eating occasions and included times given for three main meals, whereas the ND group consumed their calorie intake *ad libitum*. All participants completed a 7-day monitored food diary during the recruitment phase and received a 7-day intervention dietary plan with a daily calorie aggregate of 4800 kcal. Adherence to diet protocols was monitored weekly by a dietician.

A significant decrease ($p = 0.03$, -2%) in body mass was observed post-intervention in the TRE group (pre 67.04 ± 5.03 kg; post 65.78 ± 4.93 kg) while no significant change was observed in the ND group (pre 72.28 ± 6.24 kg; post 72.50 ± 6.45 kg). FFM was maintained in both groups (TRE: pre 56.26 ± 4.93 kg, post 56.15 ± 5.05 kg;

ND: pre 60.74 ± 5.72 kg, post 60.72 ± 7.37 kg). Free testosterone and IGF-1 decreased significantly in TRE group, whilst leucocytes decreased in both groups. Resting energy expenditure decreased in both groups but to a greater extent in the TRE group (~10% vs. ~2% for TRE vs. ND).

Exploring the functioning of the immune system and improvements in inflammatory markers as a consequence of TRE (without impeding performance), was a central aim and novel feature of this work. Short-term exercise activates an increase in pro-inflammatory cytokines that aid with cell repair, and later lead to an increase in anti-inflammatory cytokines to reduce inflammation (Lancaster and Febbraio, 2016). Endurance training temporarily impairs the immune response by causing a decrease in lymphocytes, and an increase in leucocytes and neutrophils. However, in this study, lymphocytes were increased, and neutrophils and leucocytes were decreased in both groups after the 4-week trial (Moro *et al.*, 2020). The rate of decrease was more significant in the ND group, which may suggest that TRE has a positive effect on the immune response and could benefit endurance athletes by improving the functioning of the immune system. This may be a novel direction for future research.

In agreement with my work, Moro et al. observed a decrease in body mass of a very similar magnitude in TRE, but in contrast to my work, there was no decline in FFM in TRE. Similarly, these authors observed no improvement in laboratory-based measures of aerobic performance. However, given the decrease in body mass but maintenance of peak power output, thus the peak power output to body weight ratio was increased. Given that the participants were U23 elite cyclists, an improvement in this power-to-weight ratio may result in improvements in race performance given the importance of this ratio to elite cycling performance (Jeukendrup, Craig and Hawley, 2000). Whilst this shows a potential positive outcome, this remains to be tested in a real-world setting, and moreover the intervention period was short (4 weeks) and may not represent the effects of exercise and diet during and after a sustained period of training.

The second of the two recent studies, conducted by Ashtary-Larky et al. (2021), compiled a systematic review and meta-analysis on the effects of IFast combined with resistance exercise training on body composition (Ashtary-Larky *et al.*, 2021). This paper is largely reflective of the Chapter 2; Literature Review in this thesis, with the difference being that these authors also included studies of non-athletes, resulting in a total of eight studies for analysis. Results of their analyses determined greater positive changes in body composition in the form of body mass, body mass index, body fat percentage, and fat mass in response to IFast compared to non-IFast diets, when either diet is combined with resistance exercise training. Importantly, there was no significant difference between diets for in change in FFM. Therefore, this analysis indicated that IFast (incl. TRE/TRF protocols) combined with resistance exercise training is beneficial for improving body composition and may help to maintain muscle mass when compared to a habitual dietary pattern, albeit when calorie restricted. This meta-analysis echoes another recent published systematic review that concluded that IFast combined with resistance exercise training largely maintains FFM while promoting fat loss (Keenan, Cooke and Belski, 2020). These consistent conclusions clearly show a developing pattern in the positive relationship between IFast and resistance exercise training and its impact on FFM and fat loss. As studies vary considerably in their protocols and monitoring, it is possible that variations in the EI in the different studies which may lead to differences in body composition outcomes. For example, despite the overall outcomes of the meta-analysis being positive for body mass and body fat, out of the eight studies in Ashtary-Larky et al.'s review, only two studies reported a significant decrease in body mass in the IFast group, whereas three studies showed a significant decrease in body fat in the IFast group. These outcomes, whilst significant, suggest that the effects of IFast on body composition are somewhat inconsistent, and thus should be interpreted with discretion, and require further research. However, the benefits of fasting on body composition may arise from a calorie deficit where previous studies have shown that IFast leads to an unintentional reduction in energy intake of approximate 25 to 38% (Harvie *et al.*, 2011, 2013; Varady, 2011).

A conclusion of the meta-analysis is that more studies of longer intervention with specific IFast protocols and/or IER are necessary to assess the effects of chronic IFast in the form of body composition over a cross-discipline of exercise and within defined participant populations. The extent of studies in weight loss have been observed in the confines of CER and the effects of hypocaloric diets on body composition where the relationship between lower calorie intake and changes in body mass, fat mass, and FFM are certain. In contrast, further studies in IFast protocols and/or IER would provide greater clarity and potentially expand greatly on the literature to date.

5.2 Future directions

The findings of my intervention study, the relevant studies described in the Chapter 2 Literature Review, and recent studies described in this chapter, are broadly indicative of the following conclusions. Firstly, IFast in the form of TRE can have marked effects on energy and macronutrient intakes, and therefore has the potential to alter body composition when combined with exercise training. As a number of studies cited in this thesis have shown positive results in a reduction of body mass and maintained FFM, the potential benefits for endurance athletes using TRE for the purpose of small decreases in body mass at appropriate times of the season for improving training and performance is practically meaningful. Secondly, IFast in the form of TRE does not impair adaptation to exercise training when measured as strength outcomes or indices of endurance performance. However, thirdly it is presently unclear what the impact of TRE is on FFM as results in the literature to date is varied in terms of whether exercise was endurance or strength-based, and additionally most studies conducted have been of eight weeks duration or less.

There are many questions that remain to be answered with regard to the application of TRE in athletes, but in my opinion the most pressing questions are (i) the investigation of TRE in larger numbers of female athletes, especially endurance athletes, given their greater risk for low energy availability, (ii) the investigation of the time of exercise training (whether in the fasted state or fed state) on training adaptations when exercise is combined with TRE, and (iii) the investigation of adherence to, and consequences of, TRE over periods greater than eight weeks. The answers to these questions, and others, will provide a greater insight into the practical value of TRE as tool for athletes and practitioners alike.

References

Achamrah, N. *et al.* (2018) 'Comparison of body composition assessment by DXA and BIA according to the body mass index: A retrospective study on 3655 measures', *PLOS ONE*. Edited by D.J. Handelsman, 13(7), p. e0200465. doi:10.1371/journal.pone.0200465.

American College of Sports Medicine and Academy of Nutrition and Dietetics Dietitians of Canada (2016) 'Nutrition and Athletic Performance', *Medicine & Science in Sports & Exercise*, 48(3), pp. 543–568. doi:10.1249/MSS.0000000000000852.

Anton, S.D. *et al.* (2018) 'Flipping the Metabolic Switch: Understanding and Applying the Health Benefits of Fasting', *Obesity (Silver Spring, Md.)*, 26(2), pp. 254–268. doi:10.1002/oby.22065.

Ashtary-Larky, D. *et al.* (2021) 'Effects of intermittent fasting combined with resistance training on body composition: a systematic review and meta-analysis', *Physiology & Behavior*, 237, p. 113453. doi:10.1016/j.physbeh.2021.113453.

Bergman, B.C. and Brooks, G.A. (1999) 'Respiratory gas-exchange ratios during graded exercise in fed and fasted trained and untrained men', *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 86(2), pp. 479–487. doi:10.1152/jappl.1999.86.2.479.

Bergström, J. and Hultman, E. (1972) 'Nutrition for Maximal Sports Performance', *JAMA: The Journal of the American Medical Association*, 221(9), pp. 999–1006. doi:10.1001/jama.1972.03200220033009.

Berkhan, M. (2018) *The Leangains Method: The Art of Getting Ripped. Researched, Practiced, Perfected.* Martin Berkhan. Available at: https://leangains.com/.

Bhutani, S. *et al.* (2013) 'Alternate day fasting and endurance exercise combine to reduce body weight and favorably alter plasma lipids in obese humans: Alternate Day Fasting and Exercise for Weight Loss', *Obesity*, 21(7), pp. 1370–1379. doi:10.1002/oby.20353.

Bouhlel, E. *et al.* (2006) 'Effect of Ramadan fasting on fuel oxidation during exercise in trained male rugby players', *Diabetes & Metabolism*, 32(6), pp. 617–624. doi:10.1016/S1262-3636(07)70317-8.

Bouhlel, E. *et al.* (2008) 'Ramadan fasting and the GH/IGF-1 axis of trained men during submaximal exercise', *Annals of Nutrition & Metabolism*, 52(4), pp. 261–266. doi:10.1159/000140517.

Braun, V. *et al.* (2020) 'The online survey as a qualitative research tool', *International Journal of Social Research Methodology*, 24(6), pp. 641–654. doi:10.1080/13645579.2020.1805550.

Braun, V. and Clarke, V. (2013) *Successful qualitative research: a practical guide for beginners*. London: SAGE.

Braun, V., Clarke, V. and Gray, D. (2017) ‘Innovations in Qualitative Methods’, in Gough, B. (ed.) *The Palgrave Handbook of Critical Social Psychology*. London: Palgrave Macmillan UK, pp. 243–266. doi:10.1057/978-1-137-51018-1_13.

Burke, L.M. (2015) ‘Re-Examining High-Fat Diets for Sports Performance: Did We Call the “Nail in the Coffin” Too Soon?’, *Sports Medicine*, 45(S1), pp. 33–49. doi:10.1007/s40279-015-0393-9.

Burke, L.M. *et al.* (2018) ‘Pitfalls of Conducting and Interpreting Estimates of Energy Availability in Free-Living Athletes’, *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), pp. 350–363. doi:10.1123/ijsnem.2018-0142.

Burke, L.M. and Hawley, J.A. (2002) ‘Effects of short-term fat adaptation on metabolism and performance of prolonged exercise’:, *Medicine & Science in Sports & Exercise*, 34(9), pp. 1492–1498. doi:10.1097/00005768-200209000-00015.

Burke, L.M. and Hawley, J.A. (2018) ‘Swifter, higher, stronger: What’s on the menu?’, *Science (New York, N.Y.)*, 362(6416), pp. 781–787. doi:10.1126/science.aau2093.

Burke, L.M. and King, C. (2012) ‘Ramadan fasting and the goals of sports nutrition around exercise’, *Journal of Sports Sciences*, 30 Suppl 1, pp. S21-31. doi:10.1080/02640414.2012.680484.

de Cabo, R. and Mattson, M.P. (2019) ‘Effects of Intermittent Fasting on Health, Aging, and Disease’, *New England Journal of Medicine*, 381(26), pp. 2541–2551. doi:10.1056/NEJMra1905136.

Carlson, A.J. and Hoelzel, F. (1946) ‘Apparent prolongation of the life span of rats by intermittent fasting’, *The Journal of Nutrition*, 31, pp. 363–375. doi:10.1093/jn/31.3.363.

Chaix, A. *et al.* (2014) ‘Time-Restricted Feeding Is a Preventative and Therapeutic Intervention against Diverse Nutritional Challenges’, *Cell Metabolism*, 20(6), pp. 991–1005. doi:10.1016/j.cmet.2014.11.001.

Chaouachi, A. *et al.* (2012) ‘The effects of Ramadan intermittent fasting on athletic performance: recommendations for the maintenance of physical fitness’, *Journal of Sports Sciences*, 30 Suppl 1, pp. S53-73. doi:10.1080/02640414.2012.698297.

Chow, L.S. *et al.* (2020) ‘Time-Restricted Eating Effects on Body Composition and Metabolic Measures in Humans who are Overweight: A Feasibility Study’, *Obesity (Silver Spring, Md.)*, 28(5), pp. 860–869. doi:10.1002/oby.22756.

Cohen, J. (1969) *Statistical Power Analysis for the Behavioral Sciences*. New York: Academic Press.

Cox, G.R. *et al.* (2010) ‘Daily training with high carbohydrate availability increases exogenous carbohydrate oxidation during endurance cycling’, *Journal of Applied*

Physiology (Bethesda, Md.: 1985), 109(1), pp. 126–134. doi:10.1152/japplphysiol.00950.2009.

Creswell, J.W. (2012) *Educational research: planning, conducting, and evaluating quantitative and qualitative research*. Boston: Pearson.

Dixon, C.B. *et al.* (2006) 'The effect of acute fluid consumption on measures of impedance and percent body fat using leg-to-leg bioelectrical impedance analysis', *European Journal of Clinical Nutrition*, 60(1), pp. 142–146. doi:10.1038/sj.ejcn.1602282.

Egan, B. and Zierath, J.R. (2013) 'Exercise metabolism and the molecular regulation of skeletal muscle adaptation', *Cell Metabolism*, 17(2), pp. 162–184. doi:10.1016/j.cmet.2012.12.012.

Fitzgerald, M. (2016) 'Is Intermittent Fasting A Good Idea For Endurance Athletes?', *Triathlete*, 8 February. Available at: https://www.triathlete.com/nutrition/race-fueling/is-intermittent-fasting-a-good-idea-for-endurance-athletes/ (Accessed: 23 June 2021).

Foster, C. *et al.* (2001) 'A New Approach to Monitoring Exercise Training':, *Journal of Strength and Conditioning Research*, 15(1), pp. 109–115. doi:10.1519/00124278-200102000-00019.

Gabel, K. *et al.* (2018) 'Effects of 8-hour time restricted feeding on body weight and metabolic disease risk factors in obese adults: A pilot study', *Nutrition and Healthy Aging*, 4(4), pp. 345–353. doi:10.3233/NHA-170036.

Gejl, K.D. and Nybo, L. (2021) 'Performance effects of periodized carbohydrate restriction in endurance trained athletes - a systematic review and meta-analysis', *Journal of the International Society of Sports Nutrition*, 18(1), p. 37. doi:10.1186/s12970-021-00435-3.

Gullstrand, L., Sjüdin, B. and Svedenhag, J. (2007) 'Blood sampling during continuous running and 30-second intervals on a treadmill: Effects on the lactate threshold results?', *Scandinavian Journal of Medicine & Science in Sports*, 4(4), pp. 239–242. doi:10.1111/j.1600-0838.1994.tb00434.x.

Haff, G.G. and Triplett, T.N. (2017) *Central Concepts Related to Periodization*. Available at: https://www.nsca.com/education/articles/kinetic-select/central-concepts-related-to-periodization/ (Accessed: 23 June 2021).

Hansen, A.K. *et al.* (2005) 'Skeletal muscle adaptation: training twice every second day vs. training once daily', *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 98(1), pp. 93–99. doi:10.1152/japplphysiol.00163.2004.

Harvie, M. *et al.* (2013) 'The effect of intermittent energy and carbohydrate restriction v. daily energy restriction on weight loss and metabolic disease risk markers in overweight women', *The British Journal of Nutrition*, 110(8), pp. 1534–1547. doi:10.1017/S0007114513000792.

Harvie, M.N. *et al.* (2011) 'The effects of intermittent or continuous energy restriction on weight loss and metabolic disease risk markers: a randomized trial in young overweight women', *International Journal of Obesity (2005)*, 35(5), pp. 714–727. doi:10.1038/ijo.2010.171.

Hawley, J.A. and Leckey, J.J. (2015) 'Carbohydrate Dependence During Prolonged, Intense Endurance Exercise', *Sports Medicine (Auckland, N.z.)*, 45(Suppl 1), pp. 5–12. doi:10.1007/s40279-015-0400-1.

Hemmer, A. *et al.* (2021) 'The Effects of Shift Work on Cardio-Metabolic Diseases and Eating Patterns', *Nutrients*, 13(11), p. 4178. doi:10.3390/nu13114178.

Heydenreich, J. *et al.* (2017) 'Total Energy Expenditure, Energy Intake, and Body Composition in Endurance Athletes Across the Training Season: A Systematic Review', *Sports Medicine - Open*, 3(1), p. 8. doi:10.1186/s40798-017-0076-1.

Hofmekler, O. (2007) *The Warrior Diet: Switch on Your Biological Powerhouse for High Energy, Explosive Strength, and a Leaner, Harder Body*. 2nd Revised edition (1 Dec. 2007). North Atlantic Books,U.S.

Holtzman, B. and Ackerman, K. (2019) 'Measurement, Determinants, and Implications of Energy Intake in Athletes', *Nutrients*, 11(3), p. 665. doi:10.3390/nu11030665.

Hulston, C.J. *et al.* (2010) 'Training with low muscle glycogen enhances fat metabolism in well-trained cyclists', *Medicine and Science in Sports and Exercise*, 42(11), pp. 2046–2055. doi:10.1249/MSS.0b013e3181dd5070.

Hurtford, M. (2018) 'Should Runners Be Intermittent Fasting? | MapMyRun', *Under Armour*, 20 February. Available at: https://blog.mapmyrun.com/runners-intermittent-fasting/ (Accessed: 23 June 2021).

Impey, S.G. *et al.* (2018) 'Fuel for the Work Required: A Theoretical Framework for Carbohydrate Periodization and the Glycogen Threshold Hypothesis', *Sports Medicine (Auckland, N.Z.)*, 48(5), pp. 1031–1048. doi:10.1007/s40279-018-0867-7.

Issurin, V.B. (2010) 'New horizons for the methodology and physiology of training periodization', *Sports Medicine (Auckland, N.Z.)*, 40(3), pp. 189–206. doi:10.2165/11319770-000000000-00000.

Javad Fallah, S. (2010) 'Ramadan fasting and exercise performance', *Asian Journal of Sports Medicine*, 1(3), p. 130. doi:10.5812/asjsm.34859.

Jeukendrup, A.E. (2017) 'Periodized Nutrition for Athletes', *Sports Medicine*, 47(S1), pp. 51–63. doi:10.1007/s40279-017-0694-2.

Jeukendrup, A.E., Craig, N.P. and Hawley, J.A. (2000) ‘The bioenergetics of World Class Cycling’, *Journal of Science and Medicine in Sport*, 3(4), pp. 414–433. doi:10.1016/s1440-2440(00)80008-0.

Jones, A.M. and Carter, H. (2000) ‘The Effect of Endurance Training on Parameters of Aerobic Fitness’:, *Sports Medicine*, 29(6), pp. 373–386. doi:10.2165/00007256-200029060-00001.

Joyner, M.J. and Coyle, E.F. (2008) ‘Endurance exercise performance: the physiology of champions: Factors that make champions’, *The Journal of Physiology*, 586(1), pp. 35–44. doi:10.1113/jphysiol.2007.143834.

Katsarou, A.L., Katsilambros, N.L. and Koliaki, C.C. (2021) ‘Intermittent Energy Restriction, Weight Loss and Cardiometabolic Risk: A Critical Appraisal of Evidence in Humans’, *Healthcare (Basel, Switzerland)*, 9(5), p. 495. doi:10.3390/healthcare9050495.

Keenan, S., Cooke, M.B. and Belski, R. (2020) ‘The Effects of Intermittent Fasting Combined with Resistance Training on Lean Body Mass: A Systematic Review of Human Studies’, *Nutrients*, 12(8), p. 2349. doi:10.3390/nu12082349.

Krogh, A. and Lindhard, J. (1920) ‘The changes in respiration at the transition from work to rest’, *The Journal of Physiology*, 53(6), pp. 431–439. doi:10.1113/jphysiol.1920.sp001889.

Kuipers, H. *et al.* (2003) ‘Effects of Stage Duration in Incremental Running Tests on Physiological Variables’, *International Journal of Sports Medicine*, 24(7), pp. 486–491. doi:10.1055/s-2003-42020.

Kutáč, P., Bunc, V. and Sigmund, M. (2019) ‘Whole-body dual-energy X-ray absorptiometry demonstrates better reliability than segmental body composition analysis in college-aged students’, *PloS One*, 14(4), p. e0215599. doi:10.1371/journal.pone.0215599.

Kyle, U. *et al.* (2004) ‘Bioelectrical impedance analysis -- part I: review of principles and methods’, *Clinical Nutrition*, 23(5), pp. 1226–1243. doi:10.1016/j.clnu.2004.06.004.

Lancaster, G.I. and Febbraio, M.A. (2016) ‘Exercise and the immune system: implications for elite athletes and the general population’, *Immunology and Cell Biology*, 94(2), pp. 115–116. doi:10.1038/icb.2015.103.

Laskey, M.A. (1996) ‘Dual-energy X-ray absorptiometry and body composition’, *Nutrition (Burbank, Los Angeles County, Calif.)*, 12(1), pp. 45–51. doi:10.1016/0899-9007(95)00017-8.

Lee, J.H. *et al.* (2020) ‘Intermittent Fasting: Physiological Implications on Outcomes in Mice and Men’, *Physiology*, 35(3), pp. 185–195. doi:10.1152/physiol.00030.2019.

Lessan, N. and Ali, T. (2019) ‘Energy Metabolism and Intermittent Fasting: The Ramadan Perspective’, *Nutrients*, 11(5), p. E1192. doi:10.3390/nu11051192.

Levy, E. and Chu, T. (2019) ‘Intermittent Fasting and Its Effects on Athletic Performance: A Review’, 18(7), pp. 266–269. doi:10.1249/JSR.0000000000000614.

Logue, D.M. *et al.* (2020) ‘Low Energy Availability in Athletes 2020: An Updated Narrative Review of Prevalence, Risk, Within-Day Energy Balance, Knowledge, and Impact on Sports Performance’, *Nutrients*, 12(3), p. E835. doi:10.3390/nu12030835.

Marosi, K. *et al.* (2018) ‘Metabolic and molecular framework for the enhancement of endurance by intermittent food deprivation’, *FASEB journal: official publication of the Federation of American Societies for Experimental Biology*, 32(7), pp. 3844–3858. doi:10.1096/fj.201701378RR.

Maughan, R.J., Fallah, J. and Coyle, E.F. (2010) ‘The effects of fasting on metabolism and performance’, *British Journal of Sports Medicine*, 44(7), pp. 490–494. doi:10.1136/bjsm.2010.072181.

Midgley, A.W., McNaughton, L.R. and Jones, A.M. (2007) ‘Training to Enhance the Physiological Determinants of Long-Distance Running Performance: Can Valid Recommendations be Given to Runners and Coaches Based on Current Scientific Knowledge?’, *Sports Medicine*, 37(10), pp. 857–880. doi:10.2165/00007256-200737100-00003.

Moro, T. *et al.* (2016) ‘Effects of eight weeks of time-restricted feeding (16/8) on basal metabolism, maximal strength, body composition, inflammation, and cardiovascular risk factors in resistance-trained males’, *Journal of Translational Medicine*, 14(1), p. 290. doi:10.1186/s12967-016-1044-0.

Moro, T. *et al.* (2020) ‘Time-restricted eating effects on performance, immune function, and body composition in elite cyclists: a randomized controlled trial’, *Journal of the International Society of Sports Nutrition*, 17(1), p. 65. doi:10.1186/s12970-020-00396-z.

Morton, J.P. *et al.* (2009) ‘Reduced carbohydrate availability does not modulate training-induced heat shock protein adaptations but does upregulate oxidative enzyme activity in human skeletal muscle’, *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 106(5), pp. 1513–1521. doi:10.1152/japplphysiol.00003.2009.

Mountjoy, M. *et al.* (2018) ‘International Olympic Committee (IOC) Consensus Statement on Relative Energy Deficiency in Sport (RED-S): 2018 Update’, *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), pp. 316–331. doi:10.1123/ijsnem.2018-0136.

Mujika, I. *et al.* (2018) ‘An Integrated, Multifactorial Approach to Periodization for Optimal Performance in Individual and Team Sports’, *International Journal of Sports Physiology and Performance*, 13(5), pp. 538–561. doi:10.1123/ijspp.2018-0093.

Nana, A. *et al.* (2015) ‘Methodology review: using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people’, *International Journal of Sport Nutrition and Exercise Metabolism*, 25(2), pp. 198–215. doi:10.1123/ijsnem.2013-0228.

Parr, E.B., Devlin, B.L., Radford, B.E., *et al.* (2020) ‘A Delayed Morning and Earlier Evening Time-Restricted Feeding Protocol for Improving Glycemic Control and Dietary Adherence in Men with Overweight/Obesity: A Randomized Controlled Trial’, *Nutrients*, 12(2), p. E505. doi:10.3390/nu12020505.

Parr, E.B., Devlin, B.L., Lim, K.H.C., *et al.* (2020) ‘Time-Restricted Eating as a Nutrition Strategy for Individuals with Type 2 Diabetes: A Feasibility Study’, *Nutrients*, 12(11), p. E3228. doi:10.3390/nu12113228.

Patterson, R.E. *et al.* (2015) ‘Intermittent Fasting and Human Metabolic Health’, *Journal of the Academy of Nutrition and Dietetics*, 115(8), pp. 1203–1212. doi:10.1016/j.jand.2015.02.018.

Ponto, J. (2015) ‘Understanding and Evaluating Survey Research’, *Journal of the Advanced Practitioner in Oncology*, 6(2), pp. 168–171.

Real-Hohn, A. *et al.* (2018) ‘The synergism of high-intensity intermittent exercise and every-other-day intermittent fasting regimen on energy metabolism adaptations includes hexokinase activity and mitochondrial efficiency’, *PloS One*, 13(12), p. e0202784. doi:10.1371/journal.pone.0202784.

Richardson, J.T.E. (2011) ‘Eta squared and partial eta squared as measures of effect size in educational research’, *Educational Research Review*, 6(2), pp. 135–147. doi:10.1016/j.edurev.2010.12.001.

Seiler, K.S. and Kjerland, G.Ø. (2006) ‘Quantifying training intensity distribution in elite endurance athletes: is there evidence for an “optimal” distribution?’, *Scandinavian Journal of Medicine & Science in Sports*, 16(1), pp. 49–56. doi:10.1111/j.1600-0838.2004.00418.x.

Selye, H. (1950) ‘Stress and the general adaptation syndrome’, *British Medical Journal*, 1(4667), pp. 1383–1392. doi:10.1136/bmj.1.4667.1383.

Stannard, S.R. (2011) ‘Ramadan and Its Effect on Fuel Selection during Exercise and Following Exercise Training’, *Asian Journal of Sports Medicine*, 2(3), pp. 127–133. doi:10.5812/asjsm.34760.

Stellingwerff, T. (2012) ‘Case Study: Nutrition and Training Periodization in Three Elite Marathon Runners’, *International Journal of Sport Nutrition and Exercise Metabolism*, 22(5), pp. 392–400. doi:10.1123/ijsnem.22.5.392.

Stellingwerff, T. (2018) ‘Case Study: Body Composition Periodization in an Olympic-Level Female Middle-Distance Runner Over a 9-Year Career’, *International Journal of*

Sport Nutrition and Exercise Metabolism, 28(4), pp. 428–433. doi:10.1123/ijsnem.2017-0312.

Stellingwerff, T., Boit, M.K. and Res, P.T. (2007) 'Nutritional strategies to optimize training and racing in middle-distance athletes', *Journal of Sports Sciences*, 25(sup1), pp. S17–S28. doi:10.1080/02640410701607213.

Stellingwerff, T., Maughan, R.J. and Burke, L.M. (2011) 'Nutrition for power sports: middle-distance running, track cycling, rowing, canoeing/kayaking, and swimming', *Journal of Sports Sciences*, 29 Suppl 1, pp. S79-89. doi:10.1080/02640414.2011.589469.

Stellingwerff, T., Morton, J.P. and Burke, L.M. (2019) 'A Framework for Periodized Nutrition for Athletics', *International Journal of Sport Nutrition and Exercise Metabolism*, 29(2), pp. 141–151. doi:10.1123/ijsnem.2018-0305.

Stratton, M.T. *et al.* (2020) 'Four Weeks of Time-Restricted Feeding Combined with Resistance Training Does Not Differentially Influence Measures of Body Composition, Muscle Performance, Resting Energy Expenditure, and Blood Biomarkers', *Nutrients*, 12(4), p. E1126. doi:10.3390/nu12041126.

Sutton, J. and Austin, Z. (2015) 'Qualitative Research: Data Collection, Analysis, and Management', *The Canadian Journal of Hospital Pharmacy*, 68(3), pp. 226–231.

Swart, R. (2019) *Thematic Analysis of Survey Responses From Undergraduate Students*. 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications, Ltd. doi:10.4135/9781526468666.

Swartz, A.M. *et al.* (2002) 'Evaluation of a foot-to-foot bioelectrical impedance analyser in highly active, moderately active and less active young men', *The British Journal of Nutrition*, 88(2), pp. 205–210. doi:10.1079/BJNBJN2002612.

Terry, G. and Braun, V. (2017) *Short but Often Sweet*, *Collecting Qualitative Data: A Practical Guide to Textual, Media and Virtual Techniques*. Cambridge University Press. doi:10.1017/9781107295094.003.

Tinsley, G.M. *et al.* (2017) 'Time-restricted feeding in young men performing resistance training: A randomized controlled trial', *European Journal of Sport Science*, 17(2), pp. 200–207. doi:10.1080/17461391.2016.1223173.

Tinsley, G.M. *et al.* (2019) 'Time-restricted feeding plus resistance training in active females: a randomized trial', *The American Journal of Clinical Nutrition*, 110(3), pp. 628–640. doi:10.1093/ajcn/nqz126.

Van Proeyen, K. *et al.* (2011) 'Beneficial metabolic adaptations due to endurance exercise training in the fasted state', *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 110(1), pp. 236–245. doi:10.1152/japplphysiol.00907.2010.

Varady, K.A. (2011) ‘Intermittent versus daily calorie restriction: which diet regimen is more effective for weight loss?’, *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity*, 12(7), pp. e593-601. doi:10.1111/j.1467-789X.2011.00873.x.

Varady, K.A. and Hellerstein, M.K. (2007) ‘Alternate-day fasting and chronic disease prevention: a review of human and animal trials’, *The American Journal of Clinical Nutrition*, 86(1), pp. 7–13. doi:10.1093/ajcn/86.1.7.

Witard, O.C., Garthe, I. and Phillips, S.M. (2019) ‘Dietary Protein for Training Adaptation and Body Composition Manipulation in Track and Field Athletes’, *International Journal of Sport Nutrition and Exercise Metabolism*, 29(2), pp. 165–174. doi:10.1123/ijsnem.2018-0267.

Yeo, W.K. *et al.* (2008) ‘Skeletal muscle adaptation and performance responses to once a day versus twice every second day endurance training regimens’, *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 105(5), pp. 1462–1470. doi:10.1152/japplphysiol.90882.2008.

Zemski, A.J. *et al.* (2019) ‘Same-Day Vs Consecutive-Day Precision Error of Dual-Energy X-Ray Absorptiometry for Interpreting Body Composition Change in Resistance-Trained Athletes’, *Journal of Clinical Densitometry: The Official Journal of the International Society for Clinical Densitometry*, 22(1), pp. 104–114. doi:10.1016/j.jocd.2018.10.005.

Appendices

Appendix a

TRE Study: Effects of time-restricted eating on endurance training adaptations in distance runners — March - June 2019

Participant Name: xxxx xxxxxx | **Particpant Code:** TRE021 | **Group:** Intervention

Day	Feeding Window: Began Eating	Feeding Window: Finished Eating	Training: Duration (minutes)	Training: RPE (0-10)	Weight kgs
Week Commencing (22nd - 28th April 2019)					
Monday	12:00	20:00	90 mins	5	
Tuesday	12:00	20:00	90 mins	4	76.4
Wednesday	12:00	20:00	45 mins	4	
			45 mins	6	
Thursday	12:00	20:00	60 mins	5	
Friday	12:00	20:00	45 mins	4	76.6
			30 mins	3	
Saturday	12:00	20:00	1h 50 mins	5	
Sunday	12:00	20:00	0 mins	--	
Week Commencing (29th April - 5th May 2019)					
Monday	12:00	20:00	60 mins	4	
Tuesday	12:00	20:00	45 mins	4	75.5
Wednesday	12:00	20:00	45 mins	4	
			45 mins	4	
Thursday	12:00	20:00	60 mins	4	
Friday	12:00	20:00	60 mins	4	75.5
Saturday	12:30	20:30	30 mins	7	
Sunday	12:30	20:30	0 mins	--	
Week Commencing (6th - 12th May 2019)					
Monday	12:30	20:00	2hrs	5	
Tuesday	12:00	20:00	60 mins	4	75.4
Wednesday	12:00	20:00	60 mins	5	
Thursday	12:00	20:00	40 mins	7	
			30 mins	4	
Friday	11:30	19:30	45 mins	5	75.5
Saturday	10:00	18:00	40 mins	7	
Sunday	10:00	18:00	50 mins	4	
Please provide a midway 4-day food diary at the end of next week (dates incl. Thursday 18th - Sunday 21st					
Week Commencing (13th - 19th May 2019)					
Monday	10:00	18:00	50 mins	4	
Tuesday	10:00	18:00	50 mins	7	75.9
Wednesday	10:00	18:00	50 mins	4	
Thursday	10:00	18:00	50 mins	4	
Friday	12:00	20:00	50 mins	6	76.3
Saturday	13:00	21:00	85 mins	4	
Sunday	12:00	20:00	60 mins	4	
******** Have you completed your midway food diary? ********					
Week Commencing (20th - 26th May 2019)					
Monday	12:00	20:00	0 mins	--	
Tuesday	12:00	20:00	20 mins	8	75.9
Wednesday	12:00	20:00	60 mins	4	
Thursday	12:00	20:00	60 mins	4	
Friday	12:00	20:00	60 mins	4	75.5
Saturday	12:00	20:00	45 mins	4	
Sunday	12:00	20:00	60 mins	4	
Week Commencing (27th May - 2nd June 2019)					
Monday	12:00	20:00	60 mins	4	
Tuesday	12:00	20:00	30 mins	8	75.2
Wednesday	12:00	20:00	60 mins	4	
Thursday	12:00	20:00	80 mins	4	
Friday	12:00	20:00	70 mins	4	75.3
Saturday	12:00	20:00	2hrs	5	
Sunday	12:00	20:00	80 mins	7	
Week Commencing (3rd - 9th June 2019)					
Monday	12:00	18:00	70 mins	4	
Tuesday	12:00	18:00	60 mins	7	75.4
Wednesday	12:00	18:00	70 mins	--	
Thursday	12:00	18:00	60 mins	4	
Friday	12:00	18:00	2hrs	4	75.4
Saturday	13:30	21:30	0 mins	--	
Sunday	11:00	19:00	70 mins	5	
Week Commencing (10th - 16th June 2019)					
Monday	12:00	20:00	70 mins	4	
Tuesday	12:00	20:00	60 mins	7	75.2
Wednesday	12:00	20:00	60 mins	4	
Thursday	12:15	20:15	0 mins	--	
Friday	12:00	20:00	2hrs	4	75.1
Saturday	12:00	20:00	45 mins	5	
Sunday	12:00	20:00	50 mins	4	
Week Commencing (17th - 23rd June 2019)					
Monday	12:00	20:00	60 mins	9	76

Note: Last fitness test in DCU lab (Mon 17th June 19:30)

Infromation

1. Start and Finsih time of eating
2. Duration (minutes) of training
3. Perceived Exertion (RPE) for each training session
4. Weight in kgs on Tuesday and Friday mornings only (similar time of day for each week)

(Note: It's very important to record this information daily as the accuracy of your selected RPE value may change subsequently)

This task will take about 30 seconds each day

RPE Scale (0-10)

Number Rating	Verbal Rating	Example
0	Rest	No effort at all, sitting doing nothing
1	Really Easy	Your effort is just noticeable
2	Easy	Walking slowly at your own pace
3	Moderate	Light effort
4	Somewhat Hard	It still feels like you have enough energy to continue exercising
5	Hard	Strong effort needed
6	Really Hard	Very strong effort needed
7	Very Hard	You can still go on, but you really have to push yourself. It feels very heavy and you are very tired
8	Extremely Hard	Nearing exhaustion, difficult to continue at this level of effort
9	Gruelling	Almost maximal effort, close to hardest session ever performed
10	Maximal	Absolute maximal effort, hardest session ever performed

Appendix b

TRE Study Evaluation - Intervention Group

Dear Participant,

Many thanks for your involvement in the study and for your patience in receiving your fitness tests report. The end-of-study questionnaire is now active, please click on 'Next' below and this will take you to the questionnaire. This is a short series of questions on your experience participating in the study and will take about 5-10 minutes to complete. It is important that you complete the questionnaire as the feedback will be a component of the thesis results and will conclude your participation in the study.

Once the questionnaire is completed, the fitness test report will be shared with you in Google Drive. An email will be sent to you with a link to the file. Click on the link and you will be able to view your fitness report and download as a pdf.

Email *	Participant name:
______	______

*Required

Intervention Group Questionnaire

Please answer the following questions and explain your answers. All questions (except the last) are required fields. This should take no longer than 5-10 minutes.

1. How easy or difficult was it to implement the time-restricted eating approach into your life and training commitments? *
   - ☐ Very Easy
   - ☐ Easy
   - ☐ Neither difficult nor easy
   - ☐ Difficult
   - ☐ Very difficult

2. What were the challenges, if any, to implementing the time-restricted eating approach? *

____

____

____

____

3. What, if anything, made it easy/easier to implement the time-restricted eating approach?*

4. Do you think that the time-restricted eating approach had an impact, positive or negative, on your training? *
   - ☐ Very positive
   - ☐ Positive
   - ☐ Neither positive nor negative effects
   - ☐ Negative
   - ☐ Very negative

Please explain your answer: *

5. Do you think that the time-restricted eating approach had an impact, positive or negative, on your race performances (if any)? *
   - ☐ Very positive
   - ☐ Positive
   - ☐ Neither positive nor negative effects
   - ☐ Negative
   - ☐ Very negative

Please explain your answer: *

6. Do you think that the time-restricted eating approach had an impact, positive or negative, on your performance in the lab-based running test? *
   - ☐ Very positive
   - ☐ Positive
   - ☐ Neither positive nor negative effects
   - ☐ Negative
   - ☐ Very negative

Please explain your answer: *

7. Aside from the questions above related to training and performance, did you notice any other changes in your body or general life as a consequence of the time-restricted eating approach? *

8. Will/have you continue(ed) with intermittent fasting/time-restricted eating as part of your training and lifestyle habits? *
   - ☐ Yes
   - ☐ No
   - Other:

9. Have you any comments on the challenges of recording diet and training during the study?*

Any further comments?

Appendix c

	Participant	TRE001	TRE003	TRE004	TRE005	TRE008	TRE011	TRE015	TRE016	TRE017	TRE019	TRE021	TRE028
Q1	**How easy or difficult was it to implement the time-restricted eating approach into your life and training commitments?**	Neither difficult nor easy	Easy	Easy	Neither difficult nor easy	Difficult	Easy	Difficult	Easy	Difficult	Difficult	Easy	Easy
Q2	**What were the challenges, if any, to implementing the time-restricted eating approach?**	time management and later in the evenings balancing with work.	Difficult at the start, had some slight headaches in the morning coming up to lunch time. After a week or two I adjusted to it and am doing it since although not as rigorously as before.	Evening time snacking somewhat difficult to cut out. Missed coffee in the morning too	Hard initially to get into a routine and to trust that you wouldn't starve to death!! Lack of caffeine was very tough. After 3 weeks found it pretty easy other than the lack of morning coffee. Still doing it today although not as strictly.	If you work up early in the day, it meant that you would be finished eating by early afternoon	Tough to cut out the evening eating.	No Caffeine was probably the most difficult part.	Not having breakfast first thing when you wake up. Planning mealtimes on training days.	Balancing work/life commitments with fuelling/refuelling for training/races into the eating window was difficult. Similarly, on busy work/life days, it could be difficult to eat daily calorie allocation	Most difficult part was planning your training so that the training was done in the 8-hour window period for eating so most of the time that meant not eating until 1:30pm each working day for me. Otherwise, your body gets used to it after a week of same.	None	Meeting people prior to or after the window and drinking a class of water rather than tea/coffee.

Q3	**What, if anything, made it easy/easier to implement the time-restricted eating approach?**	avoiding breakfast and commencing @10;30 am, plus focus on potential benefits.	I was doing my placement in Galway at the time so was kept busy all morning and was for the most part able to keep my mind off it although the first 2 weeks were difficult.	I'm not really a breakfast eater anyway	Got out the door in the morning a lot quicker without breakfast. Planning and preparing food the night before was key for me.	Waking up later made it easier	Once back in work it became easier as it gave a structure to your day. Weekend was tougher as the temptation of food was always around. After about a week it became the norm and the 8 h window seemed very do-able.	Knowing I was part of a group study	Keeping busy.	Flexibility of the start/end of 16-hour fast window meant you could adjust slightly if needed. For example, if your standard eating window was 12pm-8pm, on occasion you could stop at 7pm and start eating the next day at 11am.	Drink lots of water and for me having my training in the evening worked however could vary this at weekend when have more freedom.	Nothing to note	Nothing in particular just will power
Q4	**Do you think that the time-restricted eating approach had an impact, positive or negative, on your training?**	Positive	Very positive	Positive	Positive	Positive	Very positive	Positive	Negative	Negative	Positive	Neither positive nor negative effects	Negative
Q4.a	**Please explain your answer:**	Focus on eating correct food	The time I could sustain a run for without eating went from around 1:30h - 2h.	I felt I digested my food better and wasn't as bloated or full feeling as I often am in the morning and throughout the day	Lost weight. Felt good. Confident in running on empty.	It made me train earlier in the day to ensure that I could eat something afterwards	Gave a structure to my eating and concentrated my focus.	I found it gave me structure and allowed me focus on my eating habits.	I found myself feeling sluggish during training sessions in the evening time, from consuming so much food in a relatively short space of time earlier in the day.	I believe this year I ran more miles that the same period last year, and yet my race times degraded. General performance in training was slower.	I felt like I had more energy, and my body was being more economical burning CHOs and I think my lactate threshold improved.	No effect really felt	Speed work was negative, longer slower training runs had little effect. Just have food ready on return. I was fortunate to be flexible with my training times.

Q5	**Do you think that the time-restricted eating approach had an impact, positive or negative, on your race performances (if any)?**	Positive	Very positive	Neither positive nor negative effects	Very positive	Neither positive nor negative effects	Very positive	Neither positive nor negative effects	Neither positive nor negative effects	Negative	Positive	Neither positive nor negative effects	Negative
Q5.a	**Please explain your answer:**	PB's in 10 km & half marathon this year	Marathon time came down 30 mins from the previous year.	Very hard to say, possibly positive but hard to say if I just wasn't running well at the time. Would need to do it for longer to have true comparison	PB's in 3 consecutive 5ks, poor race in 10 milers, but big PB's in half and full marathon.	I could tell no difference	Increased interest in training coupled with weight loss led to better race times.	I think during the study I was at my peak season performance.	Unfortunately, I did not compete in any races during the 8-week period to make a comparison.	Race times were slower. Dunshaughlin 10k is a good example - approx. 2 mins slower between this year and last year	I felt stronger towards end of races in that lactate was not building up as quickly in my legs as before.	Didn't see any notable improvement	Slightly negative. Restricted eating is not conducive to early morning races.
Q6	**Do you think that the time-restricted eating approach had an impact, positive or negative, on your performance in the lab-based running test?**	Neither positive nor negative effects	Very positive	Neither positive nor negative effects	Positive	Negative	Positive	Neither positive nor negative effects	Neither positive nor negative effects	Negative	Positive	Positive	Neither positive nor negative effects

Q6.a	**Please explain your answer**	First Lab test was the best before time-restricted eating approach	Happy with improvement within that time period during the busy college year	Same of a couple of tests is quite small. Hard to know if how I was feeling in the day would supersede any impact of the time restricted eating. My gut would be maybe a small gain	Hard to know. I think I was uninjured, and my training was really good so that certainly played its part. I think the real benefits came by keeping it going for the months afterwards. I do think my last test was my best - so probably a mix of this test, and training	My results were poorer following the approach	Same as above. Increased training led to better times. Pre-test meal was good, and I felt energetic for the testing.	I didn't feel I performed well on the second and third test although I have no idea of the results.	I feel all three tests were roughly the same.	The paces/gradients achieved were slower/fewer	I felt fitter and my test result seemed to improve over the months. My lactate threshold I think improved.	Felt great on second test, was surprised when it was called off early	We had the same meal before the test. Rightly or wrongly my focus is always on the last thing I eat not what I ate previously to my last meal.
Q7	**Aside from the questions above related to training and performance, did you notice any other changes in your body or general life as a consequence of the time-restricted eating approach?**	Healthier choice eating, slightly leaner	Not having to spend as much time having to think about when to eat next. In final year now and is really working to my benefit. Able to get lunch at 1 in college & dinner in the evening to keep me going all day. Last year	I got my body and certainly digestion functioned better	Half a stone weight loss and I've maintained it. Even after summer hols didn't put the weight back on which is unusual for me	No changes in my body or general life were noticed because of this approach	Felt better within myself. Lost weight and the eating plan felt like it put a positive focus on your day-to-day life. Had more energy.	No, I think there wasn't any significant changes.	The need for snacking was cut down to a minimum. Overall eating habits were better.	Felt leaner. Eat fewer sweet foods. Possibly related! Energy levels throughout the day felt more balanced	I felt like I was not craving food as much and I also saved time in mornings not eating breakfast going to work!	Maybe more defined body shape not sure	I felt lighter around the chest. I was hungry in the 30 to 45 minutes before my window began. Felt light headed at times although that may have just been coincidental.

			would have a number of meals throughout the whole day										
Q8	**Will/have you continu(ed) with intermittent fasting/time-restricted eating as part of your training and lifestyle habits?**	Yes	Yes	No, but I intend to give it another go as I did generally feel better when doing it	Yes	No	Yes	Yes	No	Make a conscious effort to fast for at least 12 hours	No	No	Elements of it, Stopped eating after 8pm when possible
Q9	**Have you any comments on the challenges of recording diet and training during the study?**	Still struggle to calculate calorie intake and determine requirement	Important to get into a routine of logging it after each meal or as soon as you can afterward. I found myself breaking the fast sometimes during the summer as I would have lunch at work at 1 but could be away all day then doing different things & might be home until 10-11 to get my dinner. Easier to do	Need to be disciples with good note taking. I found going to the granular detail of weights etc not practice and too hard to consistently do	Would need to have the request for 4 day eating in advance. Very hard to do it looking back as it is so detailed.	No comments	No	The diet sheet was easy to complete	No, I found the excel sheet quick and easy	Easy to record	It was fine, just required discipline	Really enjoyed it	No

			the 1-9 eating window if you have a predictable lifestyle but this isn’t always realistic.										
Q9.a	Any further comments?	Thank you for being part of study evaluation	Overall, the experience has been hugely positive for me. I find it a huge help this year because I'm able to stay in college late to get my work done and don't have to be tied to going home for dinner at 6-7 like last year, I'm finding this college year very difficult, so this is a big help. Thanks for your advice and help throughout.	Thanks very much for the experience. I enjoyed taking part in the study and hope you got meaningful results either way.	Delighted to have done it. I think it kicked started my year			I enjoyed participating although I didn't enjoy not having caffeine. I find a coffee or tea can prevent the urge to eat. I was disappointed not to receive my lactate threshold and VO_2 after the final test was carried out. It would have benefited me during my marathon training.		Whilst I feel I didn't get a performance benefit; it was a good and educational experience.	Enjoyed taking part in this study immensely. Thanks to Henry and his team for allowing me take part. Hope it gave some good research and insight.	No	