The effect of an 8-week low carbohydrate high fat diet on maximal strength performance, body composition and diet acceptability in sub-elite Olympic weightlifters and powerlifters

Simon Chatterton

A thesis submitted to Auckland University of Technology in fulfilment of the requirements for the degree of Master of Sport and Exercise

2015

School of Sport and Recreation

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed ....

Date ………………………………………..

ACKNOWLEDGEMENTS

This thesis was completed with the commitment and help of many others.

Firstly, to my primary supervisor, Caryn Zinn, thank you for your time and patience in teaching me more and more about nutrition. Your knowledge and support led me to this topic and continued throughout the whole thesis; I could not have asked for a better supervisor. To my secondary supervisor, Adam Storey, thank you for providing valuable insight into the world of competitive weightlifting and the physiology of the sport. Also, you helped throughout the writing stages to provide further clarity for readers. Thank you, Eric Helms, you have been my main 'go-to guy' for any urgent questions and have spent many hours systematically helping me with research design and collection. I could not have completed this thesis without you. Scott Duncan, thank you for your knowledge of statistics and your advice throughout the data analysis process.

I would like to thank Andrew Kilding for his efforts in ultrasound scanning many participants and being flexible around his many other commitments. Lee Bridgeman and Scott Brown, I really appreciate your help with skinfold measurement throughout the data collection process.

To my participants: your commitment to this study is beyond a simple thank you. I have the utmost respect for each of you as 16 weeks of contact during this study required resilience and diligence throughout the dietary changes. The accuracy of your recordings of multiple measures was amazing.

Finally, to my family and friends, the many people who helped and supported me throughout this process. Mum and Dad, I thank you for your love and support that have helped to further my career dreams.

LIST OF ABBREVIATIONS

DALDA	Daily Activity and Lifestyle Demands in Athletes
CRD	Carbohydrate Restriction Diet
LCHF	Low Carbohydrate High Fat
LFHC	Low Fat High Carbohydrate
LDLc	Low Density Lipoprotein
HDLc	High Density Lipoprotein
CVD	Cardiovascular Disease
TC	Total Cholesterol
sdLDL	Small Dense Low Density Lipoprotein
lbLDL	Large Buoyant Low Density Lipoprotein
SD	Standard Deviation
SFA	Saturated Fatty Acids
KD	Ketogenic Diet
VLCD	Very Low Carbohydrate Diet
RCT	Randomised Control Trial

Chapter 1: Introduction

In the current sports nutrition literature there is a lack of insight into the weight loss procedures for weight-restricted power and strength athletes (e.g. Olympic weightlifters and powerlifters). Broadly speaking, methods of rapid weight loss such as severe caloric restriction, dehydration, purging, sauna sessions and the use of laxatives are still practiced, with only a few athletes leaning towards safer, more gradual weight loss practices. In addition to the health concerns associated with rapid weight loss methods, there is also a performance element, as rapid weight-loss schemes have been associated with significant decrements in strength performance, whereas longer gradual weight loss will preserve or allow for an increase in strength performance (Garthe, Raastad, Refsnes, Koivisto, & Sundgot-Borgen, 2011). Most gradual approaches involve the reduction of calories, which primarily comes from a reduction in fat as fat is very calorie dense. There is a 'best practice' approach which works for many athletes, but it is often associated with feeling hungry. An alternative approach for athletes who experience hunger issues could be a low carbohydrate high fat (LCHF) diet, whereby a desired weight loss can be achieved through a spontaneous reduction in calories from an increase in satiety.

As a disparity exists between the current literature and the various weight loss strategies used by competitive athletes, the question still exists regarding the optimal method for weight loss in competitive strength and power athletes. Instead of drastically reducing calories or sweating away all undesired bodyweight, a simple change in switching from a carbohydrate-dominant diet to a fat-dominant diet could be a worthwhile option to consider in order to increase the satiety of the weight-loss diet. Previous research has reported a spontaneous calorie reduction can occur during an LCHF diet, reducing bodyweight, while strength and power performance is maintained (Paoli et al., 2012; Sawyer et al., 2013b). An LCHF diet is where there is an extreme restriction of carbohydrate-based foods (50-130 g.kg.day) and an unlimited consumption of fat and protein (Feinman et al., 2015). However, there has only been limited research in this area and many questions still remain regarding its suitability to the energy demands of anaerobic-based sports and whether such diets can be adhered to by these athletes. Therefore, more comprehensive research is needed to investigate the application of such a diet and if it has any benefit for strength and power performance.

Thus, my research design will help to quantify what effects an 8-week LCHF diet (1.0g.kg.day) has on relative and absolute strength performance, anthropometrics and diet acceptability in sub-elite Olympic weightlifters and powerlifters. The aim of this study is to determine if both strength performance and lean muscle mass can be maintained while losing undesirable bodyweight. In addition, through qualitative measures of what the athletes are experiencing during the diet, the study will determine if the diet is appropriate for this particular cohort.

Purpose Statement

The purpose of this thesis is to illuminate the overall experience of the LCHF diet from the individual athlete's perspective and to provide a starting point for further research in this area. The results of this investigation will add to the limited body of knowledge regarding the implementation of LCHF diets for weight-restricted strength and power athletes. By using the athletic population of sub-elite Olympic weightlifters and power lifters, further insight will be gained into the effects of LCHF on anaerobic exercise performance, body composition and psychology throughout an 8-week period.

Thesis Aims

1. To review the published literature to determine the effects of LCHF diets on resistance-based exercise performance, anthropometry and psychology in trained individuals.
2. To investigate the effect of an 8-week LCHF diet on strength performance, body composition and psychological components in competitive Olympic weightlifters and powerlifters.

Study Limitations

1. During the intervention phase, all participants were instructed to follow the prescribed macronutrient guidelines. In addition, all participants were told to truthfully record any deviations in their daily diet that may have occurred. However, full compliance with these rules could not be guaranteed.
2. Participants who were new to food recording through the mobile phone application, My Fitness Pal, may have produced some inaccuracies through mislabelled food items in the applications data base. In addition inaccuracies may have also occurred in the measuring of their food portions.
3. As this study had a long intervention period, there was difficulty in recruiting competitive athletes. In addition, the timing of this study may not have coincided with an ideal period in their training cycle. Participants were on undulating periodisation, where they would increase their training volume over a couple of weeks before one week of de-loading. One participant went through a heavy linear periodisation before de-loading and peaking for the post-LCHF intervention 1RM testing. Another participant was in a wave-like progression and similar to the previously mentioned participant, de-loaded before the post-LCHF intervention.
4. The nature of this study design was case study. There was no control group and participants were not blinded to the LCHF diet.

5. Participants who volunteered for this study may have had preconceived opinions prior to the study that could have influenced their experience over the 8-week intervention period.
6. The nature of a case study design is to look at the individual response to a stimulus. The study therefore naturally has the limitation that inferences cannot be made to similar population groups.

Study delimitations

1. There was minimal food given to each participant but rather guidelines and meal ideas, with the onus being on each participant to track their own dietary intake. Weekly emails as well as follow-up meetings were used to provide support and assistance with any questions over the course of the entire study. This provided a chance to see if all participants were keeping up with regular food tracking. Participants were able to contact the primary researcher via cellphone or email if they had any questions or concerns.
2. To help minimise the risk of inaccurate dietary recall, all participants underwent a thorough consultation regarding diet entry into the MyFitnessPal mobile phone application. In addition, all participants received a take-home booklet that detailed, in a step by step fashion, how to correctly enter foods as well as providing effective ways of recording entire meals and recipes.
3. As a case study design was implemented in this thesis, conventional statistics and the making of inferences did not apply. Therefore, regression analysis was used to identify any significant linear or non-linear trends associated with the data collected over the 16-week study.

Thesis format

The thesis structure is presented in a series of chapters with a narrative review, three articles that are under different stages of review, and a general discussion chapter. The narrative review (Chapter 2) will delve into the background theory behind LCHF diet in sport, safety concerns and metabolic adaptations that occur while consuming such a diet.

Chapter 3 is a narrative review article which specifically focuses on the application of an LCHF diet in weight-restricted strength and power athletes. Chapter 3 is formatted for submission to the International Journal for Sports Nutrition and Exercise Metabolism. This novel review discusses current literature pertaining to LCHF diet adaptation and its impact on strength and/or performance, body composition and psychology in resistance-trained individuals.

The details of the 8-week LCHF intervention will be discussed across two chapters. Firstly, Chapter 4 will look at what effects an LCHF diet has on strength and body composition in competitive strength and power athletes. Next, Chapter 5 will discuss the adherence to and acceptability of an LCHF diet in such athletes. These chapters are in the format required for the International Journal of Sports Nutrition and Exercise Metabolism.

The sixth and final chapter is an overall discussion of the data presented in Chapters 4 and 5 along with previous evidence reported in Chapter 3. This chapter will collectively add to the body of knowledge and suggestions for future research will be discussed.

The author contributions to the papers are as follows:

Low carbohydrate high fat dieting for strength and power athletes: a current review.
Chatterton, S., (80%), Zinn, C., (10%), Storey, A., (5%), Helms, E., (5%).

The effect of an 8-week LCHF diet on strength and body composition in competitive Olympic weightlifters and power lifters.
Chatterton, S., (80%), Zinn, C., (10%), Storey, A., (5%., Helms, E., (5%).

The effect an LCHF diet on diet adherence and mental state in competitive Olympic weightlifters and power lifters.
Chatterton, S., (80%), Zinn, C., (7.5%), Storey, A., (5%), Helms, E., (5%), Duncan, S. (2.5%).

It should be noted that within the series of chapters, three stand-alone publications are presented and therefore due to the chosen submission format, there may be some repetition. In particular, Chapter 3 includes a similar introduction to Chapter 2 and may include repetitive themes that have previously been presented in Chapter 2 around the application of an LCHF diet for strength and power athletes. Chapters 4 and 5 are derived from the same 8-week intervention study that is split into quantitative and qualitative sections. Therefore, the introduction and methods are repetitive.

CHAPTER 2 – LCHF diets within sports nutrition: background theory and application.

Introduction

LCHF eating has become a familiar topic for several population groups and its application is still widely debated in current literature. For athletic populations, enhanced fat metabolism (E. V. Lambert, Hawley, Goedecke, & Noakes, 1997; S. D. Phinney, 2004) and spontaneous calorie reduction (Sawyer, et al., 2013b) to reduce bodyweight are regarded as potential LCHF dietary benefits for athletic performance. However, some LCHF researchers have reported indifferent (Goedecke et al., 1999; S. Phinney, Birstrian, Evans, Gervino, & Blackburn, 1983) and occasionally detrimental results to athletic performance (Bergström, Hermansen, Hultman, & Saltin, 1967; Brown & Cox, 1998; Havemann et al., 2006; Horswill, Hickner, Scott, Costill, & Gould, 1990; E. V. Lambert, et al., 1997). The following chapter is a narrative review of current literature focusing on defining LCHF diets, their safety, metabolic adaptations, and their application to the sports nutrition paradigm.

Current nutrition recommended standards for athletes

Current recommendation ranges for carbohydrate consumption are 5-12 g.kg.day for athletes competing in moderate to very high duration sports (> 1 hour), and 3-5 g.kg.day for athletes competing in low duration sports (< 1 hour) (L. M. Burke, Hawley, Wong, & Jeukendrup, 2011). This prescribed carbohydrate intake is tailored towards maintaining blood glucose levels and optimising muscle glycogen storage for peak performance (L. M. Burke, et al., 2011; NZDA, 2008; Rodriguez et al., 2009). Glycogen depletion in endurance athletes is commonly associated with performance decrements (Jeukendrup, 2011). Therefore, in preparation for events, endurance athletes consume a large amount of carbohydrate (>10.g.kg.day if tolerated by the athlete) to maximise muscle and liver glycogen concentration, a behaviour also known as carbohydrate loading (L. M. Burke, et al., 2011; Jeukendrup, 2011). Carbohydrate consumption varies from moderate to very high depending on the volume of training the endurance athlete completes, i.e., a high training volume equals a high consumption of carbohydrate to maximise glycogen replenishment (Jeukendrup, 2011). During exercise, endurance athletes need to replenish glycogen stores at a rate of 30g of carbohydrates every hour for events lasting up to 2 hours and up to 60g per hour for events lasting up to 3 hours (L. M. Burke, et al., 2011; Jeukendrup, 2011). Lastly, post-exercise consumption is considered a necessity for recovery, with recommendations of carbohydrate consumption of 1.0-1.2g.kg immediately after exercise (L. M. Burke, Kiens, & Ivy, 2004) followed by 50g every 2 hours post-exercise (L. M. Burke, et al., 2011)

For strength and power athletes, guidelines suggest consumption of 4-7 g.kg.day of carbohydrate in order to prevent any detrimental effects on strength and power performance (G. Slater & S. M. Phillips, 2011). Similar to recommendations for endurance athletes, this range is used depending on the athlete's training phase (Slater & Phillips, 2011). Also, some researchers have suggested that female strength athletes can consume less carbohydrate to allow higher fat and protein consumption, without compromising performance (J. S. Volek, Forsythe, & Kraemer, 2006). Consuming more fat may be advantageous to a female strength athlete due to their greater reliance on intramuscular triglycerides and circulating fats rather than glucose during resistance-based exercise (J. S. Volek, et al., 2006). However, previous research has postulated that females generally have a low percentage of fat mass when consuming an LFHC diet (Paul, Novotny, & Rumpler, 2004). However, more research is required in this area before any gender-based guidelines for carbohydrate consumption can be made.

Defining an LCHF diet

At this early stage of LCHF research and application, there is currently no universal gold-standard definition of this way of eating; however, several definitions do exist. In essence, it is a diet where carbohydrate is restricted to below “best practice” standards (whether it be in a sports nutrition or public health paradigm), protein remains moderate and the majority of energy consumption comes from fat (Westman et al., 2007). Riley’s early definition of a CRD is a reduction of carbohydrate to below 40% of total calorie intake (Riley, 1999). This guideline itself has a limitation as a definition due to it being based on total calorie intake, thereby allowing for variability in the exact intake of grams of carbohydrate. Feinman (2015) puts forward a more precise and restrictive definition involving a carbohydrate prescription in grams, capping carbohydrate intake to 130 g.day (<26% of total calorie intake) (Feinman, et al., 2015). This has been recently proposed as an optimal threshold for an LCHF diet when prescribing regimes for diabetic patients (Feinman, et al., 2015), rather than being specifically tailored towards a sports nutrition context. Finally, the most extreme carbohydrate restriction is applied in the ketogenic diet (KD), or very low carbohydrate diet (VLCD) where carbohydrate is reduced to below 50 g.day (in research and in practice often amounting to 25-30g.day) (Feinman, et al., 2015; Riley, 1999; J. Volek & Phinney, 2012; Westman, et al., 2007). Sometimes an LCHF diet allows for unlimited consumption of fat and protein-based foods (Naude et al., 2014); however, KDs are recommended to be lower in protein, as excess amino acids can limit ketone production; thus fat intake can be up to 85% of total calorie intake (Volek & Phinney, 2012). In sports nutrition research, many different variations of carbohydrate restriction have been used in both the endurance and the strength and power context (Noakes, Volek, & Phinney, 2014; Paoli, et al., 2012; S. Phinney, et al., 1983). The term KD has also been applied without the certainty of true nutritional ketosis being achieved by objective measures (i.e., blood or urine testing) (Paoli et al., 2012).

A consensus on whether LCHF dieting has a negative or positive effect on performance is yet to be established (P.L. Greenhaff, Gleeson, & Maughan, 1987; P. L. Greenhaff, Gleeson, & Maughan, 1988; Havemann, et al., 2006; S. Phinney, et al., 1983). Additionally, without a universal gold-standard definition of what constitutes low carbohydrate, and with the diverse protocols applied in research methodologies, study comparison is limited, which further limits consensus. However, despite growing evidence of potential benefits (Lambert, Hawley, Goedecke, Noakes, & Dennis, 1997; E. Lambert, Speechly, Dennis, & Noakes, 1994; Paoli, et al., 2012; Sawyer, et al., 2013b), there is still reticence about the use of LCHF diets in mainstream circles due to the controversy associated with high dietary fat intake and restricted carbohydrate intake. This may deter athletes from adopting this diet as a strategy for competition preparation.

Safety of LCHF diets

Athletes have rarely been targeted as a population group for investigating the safety of LCHF diets; however, the general population has been well researched in this area. In general, there are four key issues that tend to be a barrier to the LCHF way of eating being adopted for any length of time. These are: 1, the belief that saturated fat from food will raise saturated fat levels in the blood, thereby increasing risk of heart disease; 2, that the increase in saturated fat will result in an increase in LDL cholesterol, which in turn will increase the risk of heart disease; 3, the confusion between nutritional ketosis and diabetic ketoacidosis; and 4, that muscle mass will be lost in athletic populations.

There is still concern by health professionals that restricting carbohydrate and increasing dietary fat, in particular SFA, could increase long-term health risks such as cardiovascular disease and stroke (Dias, Garg, Wood, & Garg, 2014; Siri-Tarino, Sun, Hu, & Krauss, 2010). However, recent meta-analyses have challenged the saturated fat-heart disease relationship (Harcombe et al., 2015; Siri-Tarino, et al., 2010). Both analyses identified SFA as having no direct relationship with the prevalence of disease (Siri-Tarino, et al., 2010). Past research has identified a correlation between saturated fat and heart disease, but has never shown a cause and effect relationship. This correlation-based research has led to the negative stance towards saturated fat (Mensink & Katan, 1992). Two key feeding studies (RCTs) have been undertaken, clearly indicating the lack of relationship between saturated fat in food and saturated fat in the blood (Forsythe et al, 2010; Forsythe et al., 2008). In these studies carbohydrate intake was set to below 20% of total calorie intake and fat intake was increased to the majority of total daily calorie intake. Lower levels of circulating serum SFA were observed due to the higher rate at which it is burned when compared with individuals on a high carbohydrate, low fat diet (Forsythe et al., 2010; Forsythe et al., 2008). Participants in these studies consumed two to three times the amount of SFA compared to those on a low fat diet, yet showed significantly lower circulating SFA levels. While these studies were not undertaken in the context of sports nutrition, they do, however, show an important proof of concept relating to the mainstream hypothesis that dietary SFA has a direct impact on blood levels of SFA. Amidst this ongoing debate, one common theme which brings people into agreement is the fact that the combination of a high fat, high carbohydrate and high calorie diet (otherwise known as the “Standard American Diet”) can be harmful as it forces an increased hormonal drive, where fat is stored rather than oxidised (Grotto & Zied, 2010; Mattson et al., 2014; J. S. Volek et al., 2009)

The blood cholesterol sub-fractions of HDLc, LDLc and TC are the standard lipid subclasses that are monitored in contemporary medicine and viewed as markers associated with cardiovascular health and disease risk (Castelli, 1996). The mainstream point of view is that when LDLc increases, so too does the risk of CVD (Castelli, 1996). However, increasing evidence suggests that sub-classing of LDLc by size as sdLDL and lbLDL, as well as particle number, can provide a better indicator of CVD risk (Dallmeier & Koenig, 2014; Mora, 2009). Researchers in this area have shown an independent association between a high level of sdLDL (R. M. Krauss, 2014) and an increased risk of myocardial infarction (Austin et al., 1988). LFHC diets tend to reduce LDLc to a greater extent than LCHF diets (Hu et al., 2012); however, LCHF diets have been reported to be more effective than LFHC diets in reducing sdLDL particles and triglyceride while increasing HDL levels (R. Krauss, Blanche, Rawlings, Fernstrom, & Williams, 2006; J. S. Volek, et al., 2009). However, there is still some controversy over whether sub-classing LDLc is necessary, as opposing evidence has reported lbLDL may increase atherosclerosis, independent of sdLDL (Dallmeier & Koenig, 2014; Mora, 2009). It is important to note that no studies involving LCHF diets have reported any statistically significant increase in cardiac and/or metabolic syndrome risk factors (J. Volek, Gomes, & Kraemer, 2000; Westman, Yancy, Edman, Tomlin, & Perkins, 2002). In Volek et al.'s (2000) study, participants were prescribed an LCHF diet that consisted of 5-10% carbohydrate and 65-70% fat as percentages of total dietary intake (~15% SFA of total calorie intake). After eight weeks, there was a decrease in absolute body weight, no change in LDL levels, and a favourable increase in HDL levels. Similarly, Westman et al. (2002) found that after six months on an LCHF diet, 41 overweight and obese participants significantly decreased their body weight, LDL cholesterol and triglycerides whilst increasing their HDL cholesterol. In addition, researchers found that a longer term (12 months) LCHF diet can effectively and safely be prescribed (Stern et al., 2004). However, a possible exception may exist for individuals who have familial hypercholesterolemia, a disease where a gene mutation causes a defect in LDL catabolism. These individuals should be cautious with the amount of saturated fat consumed (Hopkins, 2003). While research has not focussed specifically on the prescription of an LCHF diet for those with familial hypercholesterolemia; evidence has shown that a diet high (32%) in vegetable- or fish-based fats reduced LDL by 30% in familial hypercholesterolemia participants (Friday, Failor, Childs, & Bierman, 1991). While the diet employed in this study does not fully emulate that of an LCHF macronutrient profile, it does indicate that perhaps an LCHF diet may still apply for those with familial hypercholesterolemia, but with an emphasis on a diet that is dominated by unsaturated fats versus foods high in SFA.

Another misinterpretation related to LCHF dieting is the difference between nutritional ketosis and 'diabetic' ketoacidosis (J. Volek & Phinney, 2012). These are two entirely different states. A ketone is a water soluble molecule produced in the liver from fat when carbohydrate is restricted or when the body is in a fasted state. Nutritional ketosis is a harmless state (defined as blood ketone levels that are usually within a range of 1.0-3.0 mmol/L), whereas 'diabetic' ketoacidosis is a potentially fatal state seen in people with poorly controlled type 1 diabetes (defined as blood ketone levels rising above 10.0 mmol/L). In metabolically well-regulated individuals, a rise in blood ketones through increasing dietary fat and restricting carbohydrate involves a safer and smaller increase in blood ketones, ten times less than is seen in diabetic ketoacidosis (Phinney et al., 2004; Voley & Phinney, 2012).

Another key concern is apprehension over maintenance of lean muscle mass during an LCHF diet (Manninen, 2006). This is largely due to the notion that as carbohydrate intake is limited, there is a reduction in insulin (the hormone responsible for storing fuel) and an increase in glucagon (the hormone responsible for mobilising fuel) resulting in an overall increase in muscle breakdown (Manninen, 2006). In addition, concern has arisen based on the potential anabolic blunting of protein synthesis pathways through the acute effect of having low glycogen levels during resistance training (Churchley et al., 2007; Creer et al., 2005). However, the mechanistic findings of Churchley et al., (2007) and Creer et al., (2005) have yet to be confirmed through longitudinal testing of body composition changes over time in an applied setting. Additionally, it has been shown that the body adapts its metabolism without the breakdown of endogenous proteins when protein is kept within daily recommendations (S. D. Phinney, 2004; Westman, et al., 2007). Furthermore, the supply of adequate calories is believed to limit degradation of proteins or oxidation of essential amino acids within the body (Mitch & Goldberg, 1996). Therefore, an LCHF diet containing adequate calories and sufficient protein may not induce a metabolic state where endogenous proteins are used to any greater degree than normal. However, this an under-researched area and more investigation of body composition changes in athletes performing resistance training is needed before any firm conclusions can be made.

From a practical standpoint, some side effects are experienced initially in some individuals during the adoption of an LCHF diet; however, these are easily prevented or eliminated through simple dietary strategies. Fatigue and dizziness are initial symptoms when carbohydrate is drastically reduced in the diet, which is due to the loss of sodium (Na) (J. Volek & Phinney, 2012). Na is an essential mineral for athletic performance (Rodriguez, DiMarco, & Langley, 2009). The maintenance of these minerals are particularly important for those who are on an LCHF diet. Volek and Phinney (2012) highlight how the body adapts from retaining water and Na to excreting them when there is little or no glucose in the diet. Therefore, during the first week after starting the diet, individuals are likely to lose a couple of kilograms due to water loss. A strategy to avoid sluggishness and replace lost Na is to add an additional 1-2g of Na to the diet in the form of salt, as well as consuming more water.

Metabolic adaptations of lowering dietary carbohydrate and increasing fat

The magnitude of carbohydrate restriction dictates the type and degree of physiological changes observed when undertaking an LCHF diet. When consuming an LCHF diet (<130 g.day), insulin becomes down-regulated as hepatic glucose output is reduced (Westman, et al., 2007). In addition, the consumption of fat causes changes to hormonal levels, particularly an increase in cholecystokinin, a gastrointestinal hormone which is involved in regulating appetite suppression through the central nervous system (De Graaf, Blom, Smeets, Stafleu, & Hendricks, 2004). However, it should be noted that protein consumption also results in the release of cholecystokinin (De Graaf, et al., 2004). This change in hormone levels can cause a spontaneous reduction in calorie intake through increased satiety (Gibson et al., 2015). Severe carbohydrate restriction in ketogenic diets prompts a rise in ketones arising from fat breakdown which changes fuel metabolism (Westman, et al., 2007). For ketone levels to rise, the body must go through a series of metabolic processes before it becomes efficient at metabolising fat (i.e., becoming fat adapted). In the early stages, the liver fails to reduce glucose output while the rate of liver glycogen synthesis attenuates, causing brief insulin resistance within the liver (Lambert, et al., 1997). Skeletal muscle adapts in the first 1 to 2 weeks, through increased activity of fat oxidative enzymes such as carnitine acyl transferase (CAT) and 3-hydroxy-acyl CoA- dehydrogenase (3-HAD) (Lambert, et al., 1997). These enzymes are responsible for converting free fatty acids into acetyl-CoA through the tricarboxylic acid cycle (Cheng, Karamizerak, Noakes, Dennis, & Lambert, 1994). In weeks 3-4, there is a two-fold decrease of muscle glycogen stores and also an increase in insulin resistance through a decrease in GLUT-4 transporters and insulin receptors (Lambert et al, 1997). After this time point, it is presumed that the body has finished the fat adaptation period and blood ketones rise to nutritional ketosis ranges. Interestingly, ketosis can also occur through intermittent fasting and very low energy diets (<800 calories per day), resulting in an increase in ketone production similar to that seen in a ketogenic diet (1-3.0mmol.L) (Anson et al., 2003; Gibson, et al., 2015), however this is not usually a protocol that is applied in order to achieve ketosis in a sports nutrition context.

Application of LCHF diets in endurance athletes

Endurance athletes typically consume a high amount of carbohydrate to fuel high volumes of aerobic exercise (Burke & Hawley, 2002). However, it has been proposed that ultra-endurance athletes (specifically ultra-marathon runners) may find an LCHF diet advantageous as long term (>2 weeks) adaptation can result in changes to their fuel utilisation from glucose to free fatty acids, sparing glycogen during submaximal exercise (Goedecke, et al., 1999; Lambert, et al., 1997). By limiting muscle glycogen depletion through enhanced fat utilisation, long duration submaximal aerobic performance may be enhanced (E. Lambert, V., J. Hawley, A., J. Goedecke, T. Noakes, & S. Dennis, C., 1997; S. Phinney, et al., 1983). However, LCHF diets may limit maximal aerobic performance (L. Burke & Kiens, 2006) with some evidence indicating a negative effect on high intensity work (>70% of VO_2 max). (Havemann, et al., 2006; S. Phinney, et al., 1983) and Phinney et al. (1983) highlighted that a lack of CHO could limit anaerobic ability at high intensity exercise. Therefore, there may be a trade-off of having an enhanced submaximal ability with enhanced FFA mobilisation against having a less capable anaerobic output. Other evidence shows no change in performance using this dietary approach (E. Lambert, et al., 1994). In addition, during both LCHF and ketogenic diet conditions, it is also hypothesised that endurance athletes may benefit from a drop in body fat and maintenance of lean muscle mass resulting in a greater power to weight ratio (J. S. Volek, Noakes, & Phinney, 2015). However, the benefits of this approach tend to be relegated only to ultra-distance athletes and current research remains inconclusive in this area.

An editorial on LCHF for endurance athletes found that 11 studies in the past 30 years have reported beneficial effects, no effect or detrimental changes to endurance performance (Noakes, et al., 2014). LCHF research in endurance sports has conclusively found that an LCHF diet allows for fat adaptation, but no concrete practical performance improvements have come out of the research. Some individual responses to the diet have shown dramatic benefits in fat metabolism, and are worth further investigation (Phinney et al., 1983). In addition, recent evidence suggests fat adaptation can reduce oxidative stress and recovery time (Shimazu et al., 2013). The mechanism behind this potential benefit is yet to be identified, but a ketogenic diet may increase a protective transcription factor (Nrf-2) that detoxifies damaged cells (Milder & Patel, 2012). To date, there have been no human trials in this area. While reduced oxidative stress may not necessarily have a direct effect on performance, it may be better for optimal cellular health in a more general sense. Future research on long term (> 6 months) LCHF adaptation is needed in order to draw definitive conclusions on endurance performance, body composition and oxidative stress (Noakes, et al., 2014). Phinney et al's (1983) work is the only study that incorporates an intervention protocol of any substantial length of time to assess true fat adaptation in athletes (i.e., 4 weeks), the likely reason for this being that these studies, if undertaken rigorously, are notoriously difficult, and expensive, to undertake. However, they are desperately needed in order to advance this area of work.

Application of LCHF diets in strength and power athletes

Comparatively, greater investigation of the utility of LCHF diets for endurance performance has been undertaken when compared to strength and power performance due to the rationale of attempting to increase fuel efficiency. However, strength and power athletes, such as weight-class restricted weightlifters, may benefit from LCHF diets through reductions in total body weight and fat mass while maintaining lean muscle mass, thereby improving relative strength (Paoli, et al., 2012; Sawyer et al., 2013a; Sawyer, et al., 2013b). Admittedly, research in this area to date is in its infancy (Haff & Whitley, 2002) and definitive conclusions and guidelines have yet to be established. However, manipulation of the macronutrient content of a weight-class restricted strength and power athlete's diet could be a better solution to reducing body weight for competition than some of the current practices of these athletes, which are unsafe and potentially harmful to performance (Paoli, et al., 2012). Some weight-class restricted athletes rapidly drop body weight through various, often undesirable, methods to achieve the required weight for competition (Anderson, Barlett, Morgan, & Brownell, 1995). Such methods include severe caloric restriction, dehydration, purging, sauna sessions and the use of laxatives. These methods have been observed to produce up to 13% losses in body weight before competition (Anderson, et al., 1995; Artioli et al., 2010; Oppliger, Steen, & Scott, 2003). This rapid loss of weight can have severe health consequences, and can even be fatal, as in the case of three college wrestlers who died as a result of severe dehydration and hyperthermia before competition in 1997 (Artioli, et al., 2010). The use of rapid weight loss techniques is more commonly found in lower weight classes and safer, gradual weight loss protocols are rarely taken into consideration (Artioli, et al., 2010; Mendes et al., 2013). From a practical standpoint, competitive Olympic weightlifters and power lifters are required to weigh-in only one to two hours before competition, leaving minimal time for recovery from rapid weight loss interventions (G. Slater & S. M. Phillips, 2011). Using an LCHF approach to reduce weight leading up to competition, satiety (or feeling of fullness) is likely to be increased by the addition of dietary fat, thereby causing a spontaneous reduction in calorie intake (Gibson, et al., 2015; Paoli, et al., 2012; Sawyer, et al., 2013b). The calorie reduction can cause a decrease in total body weight (through both water loss initially and fat mass) while muscle mass, strength and power performance are hopefully maintained (Horswill, et al., 1990; Paoli, et al., 2012; Sawyer, et al., 2013a; Symons & Jacobs, 1989; Van Zant, Conway, & Seale, 2002).

A roundtable discussion amongst notable sports nutrition researchers about the application of low carbohydrate diets for anaerobic athletes was published in 2001 (Haff, 2001). In this paper, literature around this topic reported little to no effect on strength performance (Mitchell & DiLauro, 1997) but rather a potential detrimental effect on anaerobic performance (P.L. Greenhaff, et al., 1987). A potential issue put forward by these researchers for anaerobic athletes wanting to gain or maintain weight during an LCHF diet was that satiety would induce difficulty with consuming an adequate amount of calories, as typically calorie intake spontaneously decreases during LCHF diets. In this roundtable discussion, no author strayed away from what is considered the best practice recommendations of consuming a high carbohydrate diet (8-10 g.kg.day) with adequate protein (1.5-1.8 g.kg.day) and fat (the remainder of calories). However, what these researchers did not discuss was the idea of the use of an LCHF diet as an alternative to the unsafe weight loss practices used by weight-restricted anaerobic athletes, which may be a strong case for its potential use in this athletic population. Chapter 3 will provide a comprehensive investigation into the current literature on the effects of LCHF diets on strength and performance.

Conclusions

An LCHF diet has the potential to be beneficial for both endurance and strength-based athletic populations from the perspective that it can result in substantial change in the metabolic pathways in the body towards the utilisation of fat as a fuel source, with consequent influence on body composition change. However, to date definitive answers on actual performance enhancement are yet to be established, causing apprehension from coaches and/or athletes about implementing such a diet. More long term (> 4weeks) LCHF research surrounding performance, body composition and recovery (through oxidative stress) for athletes is needed and if conducted will help to develop clear tangible evidence about its relevance in athletic populations.

CHAPTER 3 – Low carbohydrate high fat dieting for strength and power athletes: A narrative review

Introduction

"Making weight" for competitions is a regular practice amongst strength and power sport athletes such as Olympic weightlifters, powerlifters, boxers and wrestlers. Numerous and varied methods are used to achieve the desired weight loss for competition; however, some methods may be considered deleterious to health. Recently, LCHF eating has been shown to be successful for weight loss in the general population (Shai et al., 2008; Volek et al., 2004). However, in comparison only limited attention has been directed towards its application in a sports nutrition context, and even more so, in weight-class restricted strength and power athletes for competition preparation. Such a diet could be useful to these athletes, particularly if a loss in body weight is achieved through spontaneous calorie reduction and is accompanied by a preservation of muscle mass and maintenance of performance rather than any detrimental effects (Paoli, et al., 2012; Sawyer, et al., 2013). Despite the small amount of research available in this area (Haff & Whitley, 2002) and the fact that definitive conclusions and guidelines have yet to be established, the outcomes appear promising and are worthy of further investigation.

Common rapid weight loss practices among weight-class restricted strength and power athletes include severe caloric restriction, dehydration, purging, sauna sessions and the use of laxatives (Anderson, et al., 1995; Artioli, et al., 2010; Oppliger, et al., 2003). Using these methods, body weight reductions of up to 13% of initial body weight have been reported (Anderson, et al., 1995). This rapid loss of weight can cause severe health consequences, and even be fatal (Artioli, et al., 2010). In the sport of competitive Olympic weightlifting and powerlifting, lifters are required to weigh in only one-to-two hours before competition. Thus, the available time for recovery from rapid weight loss interventions is very limited (Slater & Phillips, 2011). In contrast, boxers or wrestlers weigh in the day prior to competition which allows for a greater recovery from dramatic weight loss (10-13% of total bodyweight) (Anderson et al., 1995). The manipulation of the macronutrient content of a weight-class restricted strength and power athlete's diet could be a healthier solution to reducing body weight for competition rather than the previously mentioned rapid weight loss methods (Paoli, et al., 2012). This manipulation of diet could be achieved using the LCHF eating approach. When carbohydrate is restricted and dietary fat is increased, satiety (or feeling of fullness) may increase, thereby causing a spontaneous reduction in calorie intake (Gibson, et al., 2015; Paoli, et al., 2012; Sawyer, et al., 2013). The calorie reduction can cause a decrease in total body weight (through glycogen and water loss in addition to fat mass) while muscle mass, strength and power performance are maintained (Paoli, et al., 2012; Sawyer, et al., 2013; Van Zant, et al., 2002). Interestingly, when calories have been purposely restricted during a LCHF diet, strength and power performance has decreased (Horswill et al., 1990). However, limited evidence suggests that LCHF diets appear to have no negative impact on strength and power performance (Sawyer et al., 2013; Paoli et al., 2012) and further research is warranted in this area. This review will examine the literature that investigates the effect of an LCHF diet on body composition, fatigue, mood, and strength and power performance in resistance trained individuals.

Methods

Systematic search criteria were used in order to obtain relevant articles in this area. Scopus, SPORTDiscus, Web of Science and Medline electronic databases were searched online. The search string (low carbohydrate OR high fat OR carbohydrate restrict* OR "macronutrient") AND diet AND (strength OR power OR "resistance train*") AND (athlete*OR perform*) was used for initial selection of manuscripts, in addition to limiting database results to peer reviewed studies of human subjects, published in English.

Once all manuscript records were obtained, initial screening consisted of: i) screening for duplicates, ii) screening titles for relevance, iii) screening the abstracts for relevance, iv) screening the full papers for exclusion and inclusion criteria and, v) reviewing the references of the included papers to find any additional relevant publications that were not included previously. If any papers were added that were found through reference checking, they then went through the screening process as if they had been found in the initial database search.

Manuscripts that were not from peer reviewed journals or that were not completed theses or dissertations were excluded. Additionally, only manuscripts that added to the progressive knowledge of the review were included. To be included, studies must have restricted carbohydrate to near or below 130g.day (Feinman, et al., 2015) with an increase in dietary fat. Participants in each study had to be resistance trained, with at least 2 years of previous resistance training experience. Each study had to measure strength and/or power performance before and after an LCHF intervention. Table 1 shows three articles that studied the effects of an LCHF diet on strength and power performance and body composition in resistance trained individuals. Due to the search only yielding three articles, a broader threshold for additional moderate carbohydrate restricted diet literature (n=4) was included to compare themes in reviewed articles; these articles are show in Table 2.

Results:

Collectively, the studies that appear in Table 1 reported no negative or positive effects on strength and power performance during an LCHF diet. Table 2 shows mixed results when resistance trained individuals underwent moderate carbohydrate restriction diets. The maintenance of muscular strength appeared to be influenced more by whether the dietary protocol included a structured calorie deficit with the addition of carbohydrate restriction, rather than carbohydrate restriction alone.

Table 1: Current literature of LCHF diet effects on strength and power performance in resistance trained individuals.

Study	Design	Participants	Length and nature of Dietary Intervention	Calorie controlled	Measures: (Body comp, strength, power, psychological)	Findings
Mitchell, et al. (1997)	Crossover study	11 recreational resistance trained males	Assigned to a HC* diet (CHO*: 7.66 g.kg day) or LCHF* diet (CHO 0.37 g.kg.day) for 48 hours. 3000-3200 kcal.day were consumed in both diets. A 2-week washout was used before treatments were reversed	Yes	Anthropometrics : pre testing, no post Strength: pre and post (5 sets of 15RM* of squat, leg press and leg extension.)	Strength was unaffected by either diet.
Sawyer, et al. (2013)	Repeated measures	31 trained individuals (16 males; 15 females)	7 days of habitual diet followed by 7 days of carbohydrate restriction (below 50g of CHO)	No	Anthropometrics: Segmental Body Composition analyser. Strength: handgrip dynamometry, vertical jump, 1RM bench press and back squat, maximum repetition bench press, Power: 30 second Wingate anaerobic test.	No significant changes to any strength measure. There was a significant increase in relative strength in hand grip and back squat due to BW* reduction. Significant BW reduction primarily due to water loss.
Paoli, et al. (2012)	Within-subject	9 high-level male elite artistic gymnastic athletes (age 21 ± 5.5),	30 days VLCKD* (4.5% CHO, 40.7% P, 54.8% F); 3 month washout; 30 days WD* (46.8% CHO, 14.7% P, 38.5% F)	No	Anthropometrics: Skinfolds Strength: hanging straight leg raise, ground push up, parallel bar dips, pull up, counter movement jump, squat jump.	Statistically significant changes in body weight, fat mass, fat percentage and lean body mass during VLCKD. No significant differences in strength performance.

*HC: High carbohydrate; LCHF: Low carbohydrate, high fat; CHO: Carbohydrate: RM repetition maximum; BW: bodyweight; VLCKD: Very low carbohydrate ketogenic diet; WD; Western diet

Table 2: Current literature of moderate carbohydrate restriction on strength and power performance in resistance trained individuals.

Study	Design	Participants	Length and nature of Dietary Intervention	Calorie controlled	Measures: (Body comp, strength, power, psychological)	Findings
Walberg et al. (1988)	Parallel group design	19 experienced resistance trained males	Assigned to either a control diet (15% P, 55% C, 30% F), MP/HC* diet (17% protein, 70% CHO*, 13% fat) or a HP/MC (35% protein, 50% CHO, 15% fat) for 7 days. All three diets were iso-energetic (75.3 kJ.kg.day).	Yes	Anthropometrics: Body fat and FFM* was measured through hydrostatic weighing. Strength assessment: Elbow and knee extensor test with cybex was used to measure muscle strength endurance.	No difference in changes to body fat between groups. Lean body mass was retained in HP/MC diet. HP/MC resulted in a decrease in muscle endurance performance.
Horswill et al. (1990)	Cross-over study design	12 well trained wrestlers	Randomly assigned to either 4 day LC* (11.4% protein, 41.9% CHO, 46.7% fat) or HC* (11.4% protein, 65.9% CHO, 22.7% fat). Before a 1 week washout before treatments were reversed.	Yes	Anthropometric: Skinfolds were measured to a sum of seven. Stimulation wrestling match: 8-15 second max arm crank sprints with 30 sec easy recoveries. Various blood measures.	Weight loss in both diets. A greater reduction in performance after a LC dietary intervention. Notes: Diet was administered through fluid. Looked at the effect of rapid weight loss on performance.
Van Zant, Conway & Seale. (2002)	Random assignment cross-over design	18 healthy moderately trained males (6 strength trained subjects)	3 weeks of either a MC/MF* diet (42% CHO, 40% Fat, 18% protein) or HC/LF diet (62% CHO, 20% fat, 18% protein). Followed by the opposite diet for another 3 weeks.	Yes	Anthropometrics: Skinfolds, bioelectrical impedance analysis, and body densitometry via under water weighing. Strength assessment: isokinetic machine, 2 sets of 30 isokinetic knee extensions. Bench press repetitions at 80% 1RM (concentric strength)	No difference in strength performance.

*MP/HC: Moderate protein/high carbohydrate; CHO: Carbohydrate; LC: Low carbohydrate; HC: High carbohydrate; MC/MF: Moderate carbohydrate moderate fat; HC/LF: High carbohydrate low fat; FFM: Free fat mass

Discussion:

Calorie restricted/controlled LCHF diets:

Mitchell and DiLauro (1997) reported no impairment of leg strength performance during the short-term LCHF diet period and no statistically significant difference in strength performance between the LCHF and HC diets (Mitchell & DiLauro, 1997). The maintenance of strength performance that was reported by Mitchell and DiLauro (1997) may have been influenced by the nature of the exercise demands as strength and power athletes generally derive most of their energy needs from the phosphagen and glycogenolysis pathways (Slater & Phillips, 2011). When performing resistance exercise for 30-40sec with 3 minutes rest, this could increase reliance on phosphagen resynthesis, reducing the energy contribution required from glycolytic pathways. However, this may be only true in a competition scenario as high volume training sessions would rely heavily on glycolytic systems for energy, whereby a LCHF may impair the quality of training. Future research is warranted to investigate this area further. Limiting this study was the short-term exposure of the diet (48 hours), as the amount of time typically taken to adapt to an LCHF diet is around 1-2 weeks and can even be as long as 4 weeks for full fat adaptation (Volek & Phinney, 2012). In addition, the lack of post-intervention weight measurement by Mitchell and DiLauro (1997), led to there being no discussion or comparison of weight loss between dietary interventions. Despite it not being a weight loss study per se, body weight is an easy variable to measure and a post-intervention weight would have added value to the study outcomes. In addition, the effect of hypothesised muscle glycogen depletion caused over 48 hours may be too minimal to cause changes in strength performance.

In comparison with studies incorporating a less restrictive carbohydrate intake, Van Zant et al. (2002), who applied a moderate carbohydrate restriction (MCR) (from 62% to 42% of total calorie intake) diet for 3 weeks, found no statistically significant decreases in strength performance after carbohydrate restriction in resistance trained individuals (Van Zant, et al., 2002). An MCR is defined as a carbohydrate intake of 26-45% of total daily calorie intake (Feinman, et al., 2015). However, when both calories and carbohydrates are restricted, as in the case of Horswill et al's (1990) MCR study on wrestlers, power performance significantly decreases during Wingate testing. Similarly, recreational bodybuilders participating in a study where they implemented an MCR during calorie restriction experienced decreases in muscular endurance (Walberg et al., 1988). In this investigation, researchers reported a greater decrease in quadriceps muscle strength endurance in the moderate (50% of total caloric intake) carbohydrate group compared to the high carbohydrate group (70% of total caloric intake group). In both groups, calories were reduced to nearly 50% of their maintenance needs. The enforced calorie reduction required both groups to consume a low fat diet (13 and 15% of total calories, respectively). The low calorie diet was combined with a "moderate" carbohydrate intake which was determined as a percentage of total calories. It appears the moderate carbohydrate group was unable to match the energy needs of the anaerobically-driven resistance exercise intervention. Therefore, when carbohydrate is reduced moderately under enforced calorie restriction, this may result in impairment of strength and power performance when compared to a calorie controlled diet without carbohydrate restriction. This notion is further supported by a recent study on protein requirements under calorie restriction (Helms, Zinn, Rowlands, Naidoo, & Cronin, 2014). In this study, when both calorie and carbohydrate restriction were concomitantly enforced, there was a decrease in peak force from an isometric mid-thigh pull.

However, when calories are maintained with either severe (Mitchell & DiLauro, 1997) or MCR (Van Zant, et al., 2002), the compensation through fat and protein consumption may prevent degradation to muscle strength and power performance.

Non-calorie restricted LCHF diets:

Two of the studies presented in Table 1 further explored the use of an LCHF diet, specifically using the protocol of *ad libitum* fat and protein intake. Both studies resulted in outcomes which showed maintained strength and power performance with weight reduction in resistance trained individuals (Sawyer et al., 2013; Paoli et al., 2012). To a limited extent, if carbohydrate is reduced, care should be taken to ensure that adequate calories from fat and protein are consumed to reap the potential benefits of LCHF while minimising any potential detriment to performance. Additionally, when both fat and protein are eaten *ad libitum*, participants naturally lower their total calorie intake through a possible increase in satiety (Sawyer et al., 2013). In contrast to Horswill et al. (1990), Sawyer et al. (2013) observed weight loss in their participants without applying caloric restriction. These participants experienced a reduction in bodyweight of 1.6-1.8 kg, which the authors stated was likely a loss in body water, rather than any other body composition component, as water is reduced alongside a reduction in carbohydrate (glycogen) storage. Similar to Mitchell et al. (1997), this study was only short term, using only recreational resistance trained males, therefore the findings seen in this population group may not be transferable to highly trained strength and power athletes. Paoli et al.'s (2012) longer-term study (30 days) reported no statistically significant decrements in strength and jump performance after a ketogenic diet, when compared to a western diet. Similar to Sawyer et al. (2013), these researchers reported a spontaneous drop of around 13% of total daily calories during the ketogenic diet intervention when compared to a western diet. This spontaneous calorie reduction significantly reduced their body fat percentage (2.6% loss) and fat mass (1.9kg loss) and a mean bodyweight loss of 1.8 kg across all participants during the ketogenic diet was achieved. The reported weight loss in gymnasts was minimal in Paoli et al.'s (2012) study. Gymnasts tend to be of a leaner physique which inherently comes with a lower absolute calorie intake when compared to other strength and power sports (i.e., Olympic weightlifting and shot put) (Slater & Phillips, 2011). Therefore, a habitually lower calorie consumption may have limited the amount of calorie reduction that was possible in this group (Paoli, et al., 2012). Because gymnasts already tend to have low body fat percentages of between 6-9% for males and 10-15% for females (Weimann, Blum, Witzel, Schwidergall, & Böhles, 1999), it may be that even a small loss in weight would have important implications for such athletes. Fat adaptation during an LCHF diet in combination with a spontaneous calorie deficit can result in an enhanced ability for the body to utilise both dietary and stored fat as fuel (Volek & Phinney, 2012). In addition, previous research has reported that a longer time spent in a calorie-reduced state can result in a greater reduction in body fat (Astrup, Larsen, & Harper, 2004; Civitarese et al., 2007). However, there is no consensus as to whether an LCHF diet can lead to a greater reduction in weight and greater fat loss than an high carbohydrate low fat diet, as both have shown similar results in previous research (Naude, et al., 2014).

LCHF diets and satiety:

A key point of discussion arising from this current research is the importance of the macronutrient composition of an LCHF diet, in particular fat and protein. As weight reduction is a desired goal in competition preparation for weight-restricted strength and power athletes, satiety plays a large role in the sustainability of a calorie reduced diet. The satiety of a diet can be affected by the composition of macronutrients within the diet, with protein having a strong influence on controlling hunger (Halton & Hu, 2004; Layman et al., 2003; Leidy, Armstrong, Tang, Mattes, & Campbell, 2010). Sawyer et al. (2013) reported not only an increase in fat consumption but an equally significant increase in protein (~50g.day) when calories from protein and fat were eaten *ad libitum* when compared to baseline. Likewise, Paoli et al. (2012) participants were instructed to consume a maximum of 5% carbohydrate in their total energy intake, with fat and protein eaten *ad libitum* during the ketogenic dietary intervention. The consumption of protein causes changes to hormonal levels, particularly cholecystokinin, a gastrointestinal hormone which is involved in regulating appetite suppression through the central nervous system (De Graaf, et al., 2004). However, it should be noted that fat consumption also results in the release of cholecystokinin (De Graaf, et al., 2004). Typically, a true ketogenic diet involves capping protein intake as excessive amino acids can be converted into glucose through gluconeogenesis along with increasing insulin levels and decreasing ketones in the blood stream (Volek & Phinney, 2012). Paoli et al. (2012) did not provide a threshold for protein intake. Participants consumed 97 g.day of fat and 84 g.day of protein on average when they were consuming a typical Western diet. When they switched to the ketogenic diet, fat and protein intake on average were 120 g.day and 200 g.day, respectively. One of the limitations of this study was that blood ketones were never measured, so whether or not these participants were truly in ketosis is not known; in fact it is unlikely due to their high protein intake (approximately 2.9g.kg.day). From a practical standpoint, it may not matter whether the diet was technically ketogenic or not, but this matters more from a study comparison perspective.

Protein consumption during a LCHF diet:

Protein intake may have an underlying importance when formulating LCHF eating for strength and power athletes. The gymnasts in Paoli et al. (2012) consumed 1.2g.kg.day of protein during their habitual diet and increased this intake to 2.9g.kg.day during the ketogenic intervention; a protein intake closer to recommendations for strength athletes undergoing caloric restriction (Helms, Zinn, Rowlands, & Brown, 2014). If the participants in Paoli et al's. (2012) and Sawyer et al's. (2013) studies had undergone protein capping (i.e., below 1.0g.kg.day, for the purpose of establishing nutritional ketosis), this may have been detrimental to the maintenance of muscle mass and consequently may have impacted performance. Helms et al. (2014) inferred that high dietary protein requirements relative to fat free mass (FFM), can be used as a protective cushioning to maintain or limit muscle loss during calorie-reduced diets. In contrast to ketogenic guidelines for general purposes, for athletes a potentially higher threshold for protein intake (>1.5.kg. day) may produce better outcomes in terms of performance and muscle mass sustainability when lowering carbohydrate (Phillips & Van Loon, 2011). In addition, during calorie restriction, a higher protein intake has been observed to better prevent decrements in mood state in strength athletes. This was the case in a study conducted by Helms et al (2014) in which the Daily Activities and Life Demands in Athletes (DALDA) and Profile of Mood States (POMS) was used to compare mood dimensions in athletes on a high vs moderate protein intake (Helms, Zinn, Rowlands, Naidoo, et al., 2014). Similarly, a study conducted on healthy University students in 2010 found participants consuming a high protein (30%), low carbohydrate (0%), high fat (70%) (HFHP) diet scored lower in hunger ratings and higher in fullness ratings when compared to higher carbohydrate (60%), low protein (10%)

moderate fat diets (30%) (Veldhorst, Westerterp, van Vught, & Westerterp-Plantenga, 2010). It should be noted that consuming no carbohydrate (0%) is near impossible as at least some carbohydrate would have been present in the vegetables that the authors listed as food consumed in the HFHP diet. The additive effect of high fat with a high protein intake, in the absence of carbohydrate, was reported to increase ketones (beta-hydroxybutyrate) and fat oxidative enzymes (carnitine palmitoyl transferase-1) more than a high protein, moderate carbohydrate low fat diet (Veldhorst, et al., 2010). It appears that both fat and protein are associated with appetite suppression (Gibson, et al., 2015; Langhans, 2008; Scharrer, 1999). Therefore, when reducing carbohydrate, a diet that reflects both a higher protein and a higher fat intake may be more effective in increasing satiety and resulting in a spontaneous calorie reduction than simply a high protein diet.

Qualitative research on LCHF diets:

An important aspect that is severely lacking in current research is qualitative information relating to the practical impact of such diets on a strength and power athlete's training and lifestyle. If this type of diet is to be adopted as a beneficial way to help athletes reduce weight while they at least maintain muscle mass, then it is important to be able to understand more about the acceptability of, and likelihood of adherence, to this way of eating. Paoli et al's. (2012) work touched on this aspect slightly by asking a brief question about their participants' experience. They reported that participants had difficulty in completing regular training sessions during the first week of the ketogenic diet; however, following the initial week, they were able to continue training without any perceived problems. Horswill et al's. (1990) and Helms et al's. (2014) MCR studies also addressed this by looking into the psychological toll on reducing both carbohydrate and calories with subjective questionnaires. Interestingly, athletes who consumed an

MCR, calorie restricted diet had a tendency to be more depressed and fatigued. This could be associated with a decrease in serotonin synthesis within the brain, decreasing mood, as carbohydrate is closely associated with serotonin regulation (Fernstrom & Wurtman, 1971). However, despite this additional psychological toll, there were no disparities between dietary weight loss interventions for RPE during strength testing (Horswill et al., 1990). The work of Klement et al. (2013) comes closest to addressing a more qualitative aspect, but still uses a quantitative data collection method (i.e. questionnaires) to assess this dimension. Physically active participants were given a short questionnaire that documented their subjective experience during a 40-day diet intervention (Klement et al., 2013). In this case-study design research, it took participants two to three weeks to get through the initial adaptation period before recovery and energy levels returned to normal. A common trend most participants described throughout the duration of the study was the inability to recover quickly from high intensity exercise. These results provide interesting insight into the feasibility of a self-directed ketogenic diet on athletic performance and warrants further qualitative investigation. When it comes to applying more in-depth methods of evaluating psychological state such as interviews or focus groups, no study to date has used such methodology.

Conclusion and Recommendations:

It is debatable whether or not a strength and power athlete should be on an LCHF diet when the presence of glucose is essential for the repeated expression of maximal force (Slater & Phillips, 2011). An LCHF diet that involves a severe reduction in carbohydrate (<50 g.day) and an increase in fat as the main macronutrient (i.e., a ketogenic diet) may not necessarily be the most appropriate LCHF protocol for strength athletes. Instead a more moderate reduction in carbohydrate i.e., 1.0-1.5g.kg.day along with a protein intake that is kept at a higher threshold that is more suitable for strength and power athletes (Slater & Phillips, 2011) may be more appropriate, particularly if it can still elicit body fat loss without risking muscle mass loss and consequent performance decrements. A diet of this nature with added flexibility may also be a more acceptable eating strategy for strength athletes. Furthermore, strength and power athletes should avoid large intentional reductions in caloric intake while restricting carbohydrate as this combination could be detrimental to performance (Horswill, et al., 1990; Walberg, et al., 1988). Both Paoli et al. (2013) and Sawyer et al.'s (2013) research indicates that a slight calorie deficit can spontaneously occur through implementation of a non-calorie controlled LCHF diet and produce fat loss and maintain muscle mass without a loss in strength.

Competitive athletes not only want to maintain performance but 'peak' in time for their competition. Some athletes may thrive under current rapid weight loss methods and go on to break records, while others may need an alternative approach to perform highly. By creating a reduction in bodyweight while minimally (if at all) affecting performance, a LCHF diet may provide a suitable alternative to methods normally used by weight-class restricted athletes attempting to make weight and peak for competition.

In future research, attention should be placed on the qualitative aspect of athletes' practical experiences while following a non-calorie controlled LCHF diet, including whether they faced any challenges physically, psychologically or socially. This data is important if these diets are to be implemented amongst this athletic group for weight loss purposes. More in-depth qualitative information is needed to gain a detailed perspective of the acceptability of non-calorie controlled LCHF diets for strength-based athletes. This could be built from participant interviews or focus groups to draw common themes from their experience of an LCHF diet. Finally, we are not aware of any LCHF research which specifically targets strength and power athletes whose performance depends on one-off expressions of maximal force or power such as power lifters and Olympic weightlifters.

CHAPTER 4 – The effect of an 8-week LCHF diet in national level Olympic weightlifters and powerlifters on body composition, strength and power performance.

Abstract:

Purpose: The effect of low carbohydrate high fat (LCHF) diets on the performance of weight-class restricted strength and power athletes, be it direct or indirect, is inconclusive. However, these diets could be an effective method for weight loss leading up to competition in these athletes. This study examined the effects of an 8-week non-calorie restricted LCHF diet on body composition and weight lifting performance in strength and power athletes. **Method:** In a case study design two sub-elite level Olympic weightlifters and three sub-elite level unequipped power lifters completed an 8-week LCHF intervention (within a 16-week overall study duration – 4 weeks monitoring either side of the intervention) with carbohydrate reduced to 1.0g.kg.day, protein maintained at pre-measured baseline levels and fat eaten *ad libitum*. Multiple 1 repetition maximum (RM) of the participants' competition lifts was collected retrospectively and at the completion of the intervention. Pre and post measures included anthropometry (sum of 8 body fat skinfolds) and ultrasound imaging of the quadriceps and triceps to assess changes to muscle thickness. **Results:** Four participants reduced bodyweight by 2.1-3.6 kgs; the weight of the remaining participant remained unchanged. Three participants' skinfolds decreased by 11.0-27.3 mm; two participants experienced minimal skinfold reduction (+8.4 and -4.0 mm). All participants experienced either a slight increase or decrease in strength performance but no change to performance was outside of their normal expected individual variability. **Conclusion:** After 8 weeks, an LCHF diet appeared to have no detrimental effect on performance, yet allowed for a reduction in body weight and skinfolds. Future research needs to target a larger cohort

from this population to further investigate possible LCHF benefits for strength and power athletes.

Key words: low carbohydrate high fat diet; strength; power; anthropometry; ultrasound; muscle thickness

Introduction:

The study of low carbohydrate high fat (LCHF) diets has become more popular as a diet strategy for addressing obesity and metabolic disease as well as having potential applications for athletic populations. Researchers studying endurance athletes have reported metabolic adaptations from LCHF diets that enhance fat metabolism, in hopes that this will lead to a subsequent increase in submaximal exercise performance (E. Lambert, V., et al., 1997; S. D. Phinney, 2004; Yeo, Carey, Burke, Spriet, & Hawley, 2011). Examining athletes consuming LCHF diets on the other end of the energy system continuum, i.e., in weight-class restricted strength and power athletes, has shown spontaneous reductions in caloric intake which can lead to reductions in total bodyweight and potentially improve the ratio of strength to weight (Paoli, et al., 2012; Sawyer, et al., 2013b).

Weight-class restricted strength and power athletes commonly train at a higher bodyweight to increase absolute strength before ‘cutting’ their weight to their specific bodyweight classification. During this cutting period, athletes attempt to retain as much strength as possible. The balance of dropping weight and maintaining strength is difficult and potentially hindered by some of the rapid weight loss practices these athletes use (Anderson, et al., 1995; Artioli, et al., 2010; Mendes, et al., 2013). These practices include severe calorie restriction and dehydration strategies such as taking laxatives and sitting in the sauna (Anderson, et al., 1995). Unfortunately, long term strategies that can mitigate performance decrements by reducing weight in a more gradual fashion (~500g.week) are rarely taken into consideration (Garthe, et al., 2011; Sundgot-Borgen & Garthe, 2011). A safer method of meeting the recommendation for gradual weight loss, through small enforced calorie reductions over time, could be the consumption of an LCHF diet. The small spontaneous calorie deficit that has been reported to occur when athletes consume an LCHF diet, combined with the expected water weight loss from carbohydrate restriction, may provide a beneficial combination for a weight-class restricted athlete attempting to make weight while maintaining performance (Sawyer, et al., 2013b).

Admittedly, the benefits of using an LCHF diet in strength and power athletes are speculative at best (Haff & Whitley, 2002), with varied evidence leading to either negative (Horswill, et al., 1990; Walberg, et al., 1988) or neutral effects on strength and/or power performance (Paoli, et al., 2012; Sawyer, et al., 2013b). The detrimental effects on strength and power performance reported in some LCHF-related studies may be due to the simultaneous combination of carbohydrate restriction and enforced calorie restriction (Horswill, et al., 1990; Walberg, et al., 1988). In such circumstances, participants may be unable to maintain performance as this restricted diet may not meet the demands of their training (Walberg, et al., 1988). However, in studies where only carbohydrate is restricted and calories from fat and protein are unrestricted, strength and power performance is maintained (Paoli, et al., 2012; Sawyer, et al., 2013b). Participants in studies by Paoli et al. (2012) and Sawyer et al. (2013) were able to drop bodyweight due to a spontaneous reduction in caloric intake, purportedly caused by higher levels of satiety from the increased consumption of fat and protein. However, it is difficult to differentiate the satiating effects of fat alone, without the contribution of a higher protein intake that typically occurs during non-calorie controlled LCHF diets (Paoli, et al., 2012; Sawyer, et al., 2013b)

Therefore, this study set out to explore the physiological changes caused by an 8-week non-calorie restricted LCHF diet in sub-elite Olympic weightlifters and unequipped power lifters. The LCHF diet comprised a carbohydrate intake of 1.0g.kg.day and a fat intake that was unlimited (i.e., consumed *ad libitum)*. Unlike most LCHF diets where protein is also eaten *ad libitum*, protein intakes were matched from the participants' baseline diets. Thus, any changes observed in performance and anthropometry were more likely to be associated directly with a higher fat consumption or reduction in carbohydrate rather than an alteration in protein intake. In addition, unlike studies which assessed strength in a more mechanistic manner, we opted to provide an ecologically valid assessment of performance. Therefore, strength was assessed on the competition lifts and retrospectively compared to recent competition performance to provide a practical outcome to be assessed by coaches and athletes.

This study also addressed a mood variable and an included a substantial qualitative component, which will be presented in Chapter 5.

Methods

Participants

Six sub-elite unequipped powerlifters and two sub-elite Olympic weightlifters volunteered to participate. As a requirement of the investigation, all participants were either 1) an Olympic weightlifting athlete who qualified within a 'C class' requirement or above according to Olympic Weightlifting New Zealand's (OWNZ) standards (OWNZ, 2015) or, 2) an unequipped powerlifting athlete with a bronze class requirements or above according to New Zealand Powerlifting

Federation's standards (NZPL, 2015). In addition, all participants were required to meet the following criteria: 1) have at least two years of competitive experience; 2) be drug free as per the 2014 World Anti-Doping Agency (WADA) prohibited list (WADA, 2015); 3) have access to a personal smart phone or computer in order to access nutrition tracking software; 4) not currently consuming a low carbohydrate diet (below 1.0g.kg.day); and 5) deemed healthy and injury-free as per a general health history questionnaire. An unequipped powerlifter had to meet the criteria set by the International Powerlifting Federation (NZPL, 2015). (See Appendix 9)

Testing procedure

Prior to participating in the study, each participant completed a consent form (Appendix 3) and a health history form (Appendix 4). Five consultations were held at integral points throughout the 16-week study. This study is presented diagrammatically in Figure 1. An initial consultation (C1) with each participant was held to provide education on tracking and monitoring procedures for their baseline (habitual) diet. During C1, an anthropometric assessment was conducted by an ISAK level 1 qualified researcher, which included an eight-site skinfold measurement, and a measure of height, weight and limb girths. During the last week of the baseline intervention a second consultation was organised (C2). C2 involved prescribing participants their personal LCHF dietary guidelines, an anthropometric assessment, and ultrasound imaging (rectus femoris and triceps muscle thickness and pennation angle). In addition, during this consultation, an additional 1RM assessment (either snatch, and clean and jerk, or back squat, bench press and deadlift) was performed if a participant's most recent competition was not within 2 months of beginning the study. Participants began their LCHF intervention phase the following week. A third consultation (C3) occurred during week 4 of the 8-week LCHF intervention, which included an anthropometric assessment and an informal discussion of their progress. The fourth consultation (C4) involved an anthropometric assessment, an ultrasound imaging collection, 1RM testing and a one-on-one interview (data presented in Chapter 5). Participants were then instructed to return to their original baseline diet and proceed for another 4 weeks. The last consultation (C5) comprised a final anthropometric assessment and post-study questionnaire (data presented in Chapter 5).

Diet tracking

Throughout the 16-week study, daily dietary intake was collected using the nutrition tracking software My Fitness Pal® mobile phone applications and website. Each participant received a My Fitness Pal guidebook (Appendix 5). The primary researcher had direct access to their diet entries, which were manually transferred into Food Works® (Xyris Software (Australia) Pty Ltd). This analysis software is based on a New Zealand database of foods and is more appropriate (and accurate) for the local context. After the 4-week baseline diet tracking period, an average weekly macro-nutrient intake was calculated, which was then identified as the participants' baseline diet. This dietary information was presented to each participant so that they could clearly identify how to proceed with their intervention diet in relation to their current intake. Prior to starting the LCHF intervention phase, participants were provided with a hard-copy comprehensive LCHF diet resource (Appendix 7) along with verbal instructions. The resource included a list of foods with their associated carbohydrate contents, meal ideas and recipes. Participants were instructed to match their baseline protein intake, reduce their carbohydrate to 1.0 g.kg.day and eat fat *ad libitum*. When the LCHF diet intervention period commenced, each participant continued to track their diet through My Fitness Pal®, which was continually monitored by the researcher and a Registered Dietitian. If the participants’ diets deviated from the LCHF recommendations they were contacted (via email or phone call) and offered additional support to help them adhere to the diet. A deviation that warranted further intervention was participants consuming above 15% of recommendations three days in a row. Support included an open phone line and email support for assistance from the primary researcher during the entire 8-week LCHF intervention. Dietary data transferred to Food Works was then analysed to determine mean grams per kilogram per day of carbohydrate, protein, fat and mean kilocalorie intake per week for the entire 16-week period.

Anthropometry assessment

Participants were required to enter the laboratory at the same time of day for each anthropometric assessment. This was to avoid daily fluctuations of bodyweight and skinfolds. In addition, the same ISAK qualified researcher that performed the initial anthropometric assessment was required to perform the participant’s subsequent anthropometry measurements. Participants’ skinfolds were measured at eight sites; triceps, biceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf (Stewart, Marfell-Jones, Olds, & de Ridder, 2011), in addition to waist, hip and arm girths, which were measured only as standard ISAK practice, with no intention of including them in the statistical analysis. The same anthropometric measuring kit was used for all subsequent measurements after the initial measurement for each participant.

Strength assessment

Strength performance data was collected on three separate occasions during the study: 1) retrospectively from records of previous sanctioned competitions within two months of the start of this study; 2) week 4 of the baseline period if the participant had not competed within two months prior to the study; and 3) during the last week of the diet intervention period. A 1 RM snatch and clean and jerk was performed by the Olympic weightlifters, and a 1RM back squat, bench press and deadlift was performed by the unequipped powerlifters. Olympic weightlifting participants performed their maximal competition lifts in a simulation competition with similar protocols used in previous research (Storey, Birch, Fan, & Smith, 2015). For a detailed description of 1RM Olympic weightlifting testing procedure refer to Storey et al. (2015). An example of the ramp protocol for Participant 2 is provided in Table 2. An IWF certified referee judged each maximal lift attempt for verification. After each successful attempt, the participant and the participants' coach would confer on the increase in load for the following attempt. Rest was monitored with 2-5 minutes between attempts and participants had a 10 minute rest between snatch and clean jerk protocols as is done in competition. Trained Olympic weightlifters have been previously reported to have very consistent performance in assessments of their 1RM snatch and clean and jerk (CV 2.3-2.7%) (McGuigan & Kane, 2004)

Table 3: Example of 1RM warm-up protocol for Olympic weightlifter with a 1RM snatch of 80kg and clean and jerk of 100kg

Sets	Reps	Load (kg)	Percentage of RM (%)
Snatch			
1	2	35.0	42%
2	2	40.0	49%
3	2	45.0	56%
4	2	50.0	63%
5	1	55.0	69%
6	1	60.0	76%
7	1	66.0	83%
8	1	72.0	90%
Clean and Jerk			
1	2	27.0	27%
2	2	37.0	37%
3	2	48.0	48%
4	2	59.0	59%
5	1	69.0	69%
6	1	80.0	80%
7	1	85.0	85%
8	1	90.0	90%

The 1RM assessment for unequipped power lifters used similar protocols to Matuszak et al. (2003). The athletes achieved their 1RM effort in 3 maximal attempts, to simulate a competition-based setting. In addition to the prescribed warm-up sets prior to 1RM attempts, an additional 1-2 warm-up sets were allowed when desired for each participants to allow a better transition from 80% to their first maximal attempt. Three-minute rest periods were given between all attempts (Matuszak, Fry, Weiss, Ireland, & McKnight, 2003) and a complete range of motion and adherence to proper technique was required at all times. Attempts were observed by a certified national level powerlifting referee (following IPF rules), who judged whether attempts were successful or not. All retrospective strength data and post-LCHF intervention testing was then collated with the participants' body weight to represent a Sinclair (Olympic weightlifter) or Wilks score (powerlifter) along with total weight lifted. Sinclair (Hester, Hunter, Shuleva, & Kekes-Sabo, 1990) and Wilks equations (Vanderburgh & Batterham, 1999) are used during Olympic weightlifting and powerlifting competitions, respectively, to compare performance across different weight classes. Thus, both absolute and allometrically scaled strength measures were obtained for each participant. Participant training volumes were collected throughout the 16 weeks.

Ultrasound imaging

Prior to the strength assessments, resting ultrasound (GE Healthcare Vivid S5) images of the quadriceps and triceps were obtained from each participant. Muscle thickness and pennation angle (for rectus femoris only) were determined from the images using measuring tools on the ultrasound scan. Rectus femoris muscle belly was located 60% down from the popliteal crease to the patellare (Blazevich, Gill, & Zhou, 2006). Imaging techniques for muscle thickness and pennation angle used a similar protocol to Blazevich et al. (2006). The triceps measurements were taken from the mid-point of the straight line joining the superior aspect of the lateral acromion border and the proximal lateral border of the head of the radius. Similarly, triceps muscle thickness of the right arm was obtained using a protocol previously described by Miyatani et al. (2000). Ultrasound has been seen as a reliable tool to measure muscle thickness area in knee extensors and elbow extensors (Miyatani, Kanehisa, & Fukunaga, 2000; Miyatani, Kanehisa, Ito, Kawakami, & Fukunaga, 2004) and the ultrasound imaging was conducted by a researcher well-trained in the use of ultrasound measurements. Three images were taken of each muscle and then analysed to determine rectus femoris and triceps muscle thickness and pennation angle. The mean measurement from three images was used as the final value for muscle thickness and pennation angle. Ultrasound measurements were taken the week prior to the 8-week LCHF intervention (C2) and during the last week of the intervention (C4).

Data Analysis:

Firstly, pre- to post-intervention change scores were expressed as percentage changes for each variable and for each individual. In addition, regression was used to identify any significant linear or non-linear trends that emerged from strength performance and skinfold measures. A non-parametric Friedman test was used to identify any statistical differences between carbohydrate, protein fat and carbohydrate over the three dietary phases of the study in all participants. All analyses were conducted using SPSS (IBM® SPSS® Statistics, version 20) using an alpha of 0.05. Raw values are presented for ultrasound images rather than regression analyses due to the lack of time points during the study for statistical analysis.

Results

Diet Analysis

Five of the original eight participants completed the 8-week LCHF intervention. Table 3 shows the demographics of these participants. Three lifters had to withdraw during the baseline period of the study due to time commitment issues or interference with competition preparation. The macronutrient and energy intakes of each participant are presented in Table 4. By design, participants reduced their carbohydrate intake from 30-48% of total calorie intake to 12-16% of total calorie intake. Comparatively, protein intake among participants showed no statistically significant ($p<0.2$) difference throughout the study, whereas carbohydrate and fat changed significantly ($p<0.02$) from baseline to LCHF intervention. As fat was eaten *ad libitum*, an increase in fat intake varied from 31-41% of total calorie intake during baseline to 51-66% of total calorie intake during the LCHF intervention period. Participant 3 had the smallest increase in fat consumption, whereas Participant 4 had the largest increase in fat consumption.

Table 4: Participant physical characteristics of unequipped powerlifters and Olympic weightlifters

Unequipped Power lifters				
Participant	Gender	Age (years)	Weight (kg)	Height (cm)
1	Male	26	76.2	166
3	Male	24	90.1	177.2
5	Male	31	91.1	184.6
Olympic weightlifters				
2	Female	24	78.5	157.5
4	Male	29	95.4	186.9

Table 5: Descriptive statistics of mean ± SD values of carbohydrate (CHO), protein, fat (in grams) and calories during Baseline, LCHF intervention and Post-intervention dietary periods (16 weeks total)

		Baseline (4 weeks)		
Participant	CHO	Protein	Fat	Calories
1	160.3 ± 16.9	159.9 ± 16.3	81.6 ± 17.2	2131.1 ± 173.0
2	167.2 ± 13.9	86.4 ± 12.2	67.45 ± 10.1	1659.4 ± 167.7
3	241.0 ± 126.1	236.2 ± 34.2	155.9 ± 23.9	3377.0 ± 645.7
4	197.0 ± 32.1	146.7 ± 14.7	69.0 ± 17.8	2031.8 ± 287.5
5	344.8 ± 25.8	167.6 ± 17.4	101.0 ± 3.7	2890.4 ± 183.9
		LCHF Intervention (8 weeks)		
Participant	CHO	Protein	Fat	Calories
1	67.15 ± 9.5	178.3 ± 19.0	125.1 ± 11.5	2167.6 ± 129.6
2	60 ± 13.0	102.4 ± 8.9	90.1 ± 15.2	1490.1 ± 150.2
3	87 ± 15.8	234.9 ± 37.8	167.6 ± 42.3	2680.7 ± 450.9
4	79.7 ± 6.7	150.9 ± 4.8	154.4 ± 13.4	2299.7 ± 114.8
5	82.4 ± 7.8	163.5 ± 12.3	197.2 ± 27.8	2692.2 ± 252.5
		Post intervention (4 weeks)		
Participant	CHO	Protein	Fat	Calories
1	150.3 ± 16.5	183.8 ± 15.6	88 ± 45.4	2275.1 ± 144.5
2	27.1 ± 8.4	106.7 ± 39.5	54.9 ± 17.4	1299.8 ± 269.3
3	192.9 ± 45.5	255.8 ± 23.2	151.4 ± 35.0	3143 ± 492.0
4	125 ± 25.7	159.6 ± 10.6	135.23 ± 23.3	2268.3 ± 288.0
5	323.4 ± 22.8	153.7 ± 3.7	121.4 ± 10.5	2930.8 ± 78.3

Figure 1 shows the daily calorie intake of each participant from the baseline phase through each week of the LCHF intervention. During Week 1, four participants' mean calorie intake reduced by 3.4-33.1%, while one participant showed an energy increase of 4.0%. Following Week 1, Participants 1, 3, 4 and 5 linearly increased their calorie intake in subsequent weeks. In Week 7, Participant 3's calorie intake rose 4.5% above baseline and then decreased to 8.1% below baseline the following week. During Week 8, Participants 1, 2, 4 and 5 finished with a daily calorie intake above their respective baseline levels. Only during the 4-week post-intervention phase were days of food tracking left unrecorded due to scheduling conflicts or periods where participants were without internet access. However, since participants were instructed to return to their habitual diets during this period, the 'missed' days were likely still representative of their baseline diets.

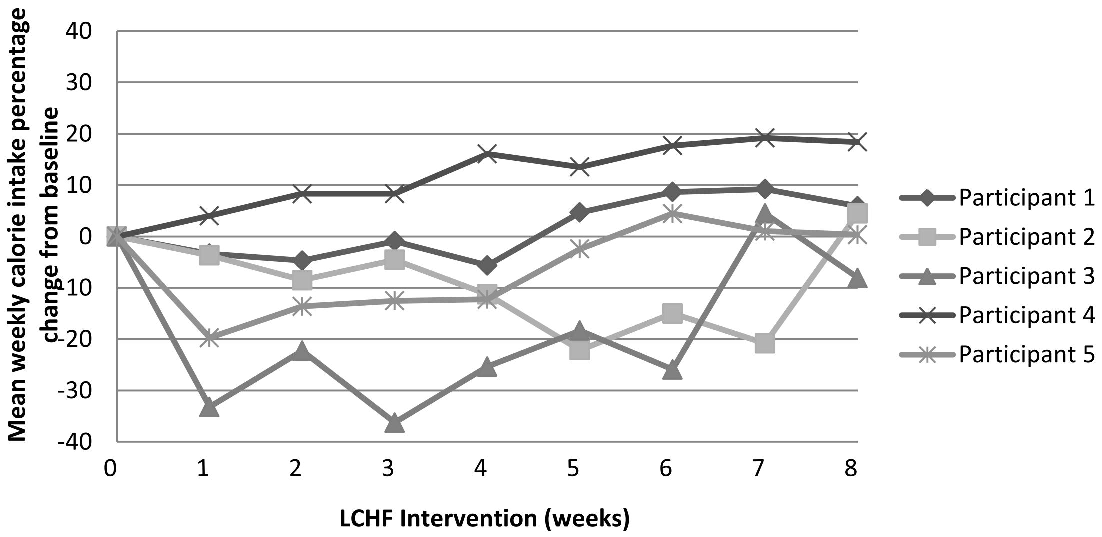


Figure 1: Percentage change of mean weekly calorie intake during LCHF intervention compared to baseline.

Anthropometry:

Curve fitting for anthropometric data showed no trends among all participants. The changes in bodyweight and skinfolds can be seen in Table 5. During the 8-week LCHF intervention, Participants 2-5 lost 2.1-3.6 kgs of bodyweight, which matched a decrease of 11-27.3 mm in skinfolds. Participant 1 (unequipped powerlifter) had little to no change in either bodyweight (-0.8kg) or skinfolds (+5.75mm). Conversely, Participant 4 (Olympic weightlifter) lost the most bodyweight (3.8kgs) and exhibited the greatest decrease in skinfolds (27.3mm/26.9%).

Table 6: Bodyweight and sum of 8 skinfold percentage changes (with raw values) from baseline, Week 4 and 8 of LCHF dietary intervention

Bodyweight (kg)				
Participant	Baseline	Intervention (Week 4)	Intervention (Week 8)	Percentage (kg)
1	76.2	76.1	75.4	-1.0% (-0.8kg)
2	78.5	76.6	76.4	-2.6 % (-2.1 kg)
3	90.1	87.4	87.8	-2.5% (-2.3 kg)
4	95.4	91.1	91.8	-3.8% (-3.6 kg)
5	91.1	88.1	88.7	-2.6% (-2.4 kg)
Sum of 8 skinfolds (mm)				
Participant	Baseline	Intervention (4 week)	Intervention (8 week)	Percentage (kg)
1	70	71	75.75	+ 8.2% (+5.75 mm)
2	188.5	185	160	- 15.1%(-25.5mm)
3	83	71	72	- 13.2 % (-11 mm)
4	101.5	71.5	74.25	- 26.9%(-27.25mm)
5	71.5	65	68.5	- 4.0% (-3 mm)

Strength performance:

Table 6 shows linear trends in retrospective strength performance for Participants 1, 4 and 5 in both absolute retrospective strength performance (RSP) (Total) and relative RSP (Wilks/Sinclair score). Participant 3 had three previous RSPs, with RSP5 qualifying the power lifter as bronze class. Participant 2's RSP showed a performance decline from RSP3 leading into the intervention phase. Participants 1-4 were able to increase their relative strength performance through maintenance or increase in absolute strength performance coinciding with the previously reported decrease in bodyweight. Participant 5's absolute and relative strength reduced through a decrease in 1RM deadlift and squat performance during post-intervention testing.

Table 7: Absolute strength performance (Total) and relative strength performance (Sinclair/Wilks score) for retrospective strength performance (RSP) data and post-intervention testing.

Participant	Metric	RSP1	RSP2	RSP3	RSP4	RSP5	Post intervention	% change (RPS 5 to Post)
1 (PL)	Total	460.0	500.0	520.0	547.5	560.0	560.0	0.0%
	Wilks Score	356.8	363.0	377.7	393.8	395.4	397.5	0.4%
2 (OWL)	Total	168.0	174.0	180.0	173.0	169.0	169.0	0.0%
	Sinclair score	202.5	210.2	217.1	208.5	198.3	200.4	0.6%
3 (PL)*	Total	X	X	452.5	467.5	542.5	557.5	2.8%
	Wilks Score	X	X	297.0	304.0	348.3	360.5	3.5%
4 (OWL)	Total	180.0	196.0	210.0	212.0	215.0	217.5	1.2%
	Sinclair score	201.6	223.9	239.0	242.4	244.7	250.7	2.5%
5 (PL)	Total	585.0	590.0	592.5	592.5	610.0	597.5	-2.1%
	Wilks score	370.0	372.8	375.8	374.3	389.2	384.3	-1.3%

Ultrasound

Table 7 shows very few changes were observed from pre- to post-ultrasound testing sessions. Those changes that were observed fell within the expected normal variation for muscle thickness (<10%) and pennation angle (<14%) (Kwah, Pinto, J, & Herbert, 2013). Only one participant had a decrease of 5 mm (10.8% decrease) in triceps muscle thickness.

Table 8: Pre- and post-ultrasound imaging of muscle thickness (mm) and pennation (degrees) for Rectus Femoris and muscle thickness (mm) for Triceps.

	Pre LCHF intervention			Post LCHF intervention		
Participant	RF MT	RF PA	T MT	RF MT	RF PA	T MT
1 (PL)	23.0	16.9	63.0	23.0	16.9	63.0
2 (WL)*	17.0	17.4	46.0	19.0	17.2	41.0
3 (PL)	26.0	11.7	70.0	25.0	11.8	71.0
4 (WL)	20.0	17.1	58.0	22.0	16.8	54.0
5 (PL)	19.0	18.6	57.0	18.0	18.5	57.0

Note: RF: Rectus Femoris; MT: Muscle Thickness; PA; Pennation Angle: T: Triceps
*Participant 2 suffered a right shoulder injury from training during the LCHF intervention

Discussion

Participants in the current study experienced a general reduction in bodyweight and maintenance in strength performance during an LCHF diet when carbohydrate consumption decreased to 1.0g.kg.day and fat consumption increased. Consistent with previous research (Paoli, et al., 2012; Sawyer, et al., 2013), the 8-week intervention LCHF diet caused a spontaneous calorie decrease in four participants, resulting in decreased bodyweight and skinfold measurements. Four participants maintained or showed a slight increase in absolute and relative strength with one participant (Participant 5) showing a small decrease in both. If unequipped powerlifters do in fact perform with a similar level of reliability to Olympic weightlifters (as reported in McGuigan et al. (2004), the decrease in strength that Participant 5 experienced could be considered within the normal level of variation. However, it should be noted Participant 5 consumed the greatest amount of carbohydrate (~3.8g.kg.day) relative to other participants during the baseline period, which may have been a factor in the performance decrement during the LCHF intervention.

From our dietary tracking analysis, it was evident that each participant was able to successfully reduce carbohydrate to 1.0g.kg.day as well as maintain their baseline protein intake (1.1-2.6 g.kg.day). Thus, the findings from the current study are novel as no study, to the best of our knowledge, has yet implemented an LCHF diet where protein was controlled. During the LCHF intervention only fat was eaten *ad libitum*. Therefore, the change in calorie consumption appears to be either due to the increase in fat or decrease in carbohydrate consumption. As expected, this spontaneous calorie reduction coincided with reductions to both bodyweight and skinfold measurements. Four out of five participants saw a varied initial drop in daily caloric intake from as little as 3% up to 33% while consuming a CHO intake of 60-90g.day during week 1 of the LCHF intervention. Previous research, which reduced carbohydrate below 50 g.day with fat and protein eaten *ad libitum*, reported a daily mean calorie reduction of 13-15% compared with participants' baseline diet over a 1 to 4 week period (Paoli, et al., 2012; Sawyer, et al., 2013b). During week 1 of the LCHF intervention, four participants increased their fat intake by 53-91% when compared to baseline consumption. It is possible that the initial reduction in calories can be attributed to an increase in cholecystokinin (CCK), an appetite-suppressing hormone that is secreted in association with an increase in fat intake (De Graaf, et al., 2004). Another mechanism for spontaneous calorie reduction could be that participants simply consumed less due to a lack of familiarity with LCHF dieting; however, we feel this was probably not the major factor as a large part of the initial consultations with participants included education on how to adopt an LCHF diet. This lack of familiarity was evident in Participant 3, who decreased fat consumption by 16% during week 1 of the LCHF intervention. In addition, Participant 4 had an unusually low calorie consumption during week 3 of the baseline period, which may have been due to inconsistent food tracking. This inconsistency may have lowered the mean weekly calorie consumption during the baseline period, which possibly affected the comparative calorie percentage changes presented in Figure 1. After the initial week of the LCHF intervention, three out of five participants spontaneously increased their fat consumption (19-31%), with two participants reducing their fat intake (12-14%) for the remainder of the intervention. The case study design of this study is particularly useful as it allows one to focus on individual responses to a dietary strategy. This has been a criticism of previous research, in particular Phinney et al. (1983), where the individual responses to an LCHF diet were masked by grouping data.

Following the initial changes to calorie consumption, bodyweight, as measured during week 4 of the LCHF intervention, reduced. This reduction can be largely associated with a reduction in body water, as glycogen depletion is coupled with water loss (Bergström, et al., 1967; Dipla et al., 2008). In addition, a calorie deficit of approximately 500kcal.day can result in 0.45 kg (1 pound) of weight loss per week if this loss of mass comes entirely from fat (Hall, 2007). Therefore, bodyweight loss may not only be attributed to water loss, but also losses in body fat, as demonstrated by a reduction in skinfolds (13.2-26.9%) in Participants 2-4.

Sustained weight loss during the LCHF intervention, while caloric intake increased spontaneously, was a novel finding. Participants 2, 3 and 4 appeared to preserve fat-free mass (FFM) as skinfolds generally coincided with weight loss, along with no change in ultrasound muscle thickness imaging. A possible mechanism to explain the maintenance of reduced bodyweight under an increasing calorie surplus could be an increase in fat utilisation and a decrease in hormonal response, in particular insulin (Lambert et al., 2002). In addition, a reduction in glycogen availability within the muscle and liver can result in a decrease in insulin receptors and Glut-4 glucose transport mRNA, while fat metabolism increases (Lambert et al., 2002). Therefore, the body may become more efficient in utilising free fatty acids for fuel, which may also drive a greater internal metabolism. Despite this possible physiological adaptation, two participants experienced a minimal change to 8-site skinfolds (-4% and +8.2%), which were both within the technical error of measurement ICC variability (<10%) of the ISAK researcher.

At the end of the LCHF intervention, all five participants spontaneously increased daily calorie consumption to above or near their baseline intake. Interestingly, from our findings the increase in calorie intake did not follow an increase in bodyweight or skinfold measurement. The gradual increase in calorie intake may have resulted from a down-regulation in satiety, primarily through leptin signalling, as body weight reduced (Morton, Cummings, Baskin, Barsh, & Schwartz, 2006). For example, a mild decrease in leptin would result in decreased satiety signalling in order to shift body weight back to normal levels (Ahima, 2008; Ahima, Kelly, Elmquist, & Flier, 1999). This response would be associated with an increase in calorie consumption (Ahima, 2008; Ahima, et al., 1999). We believe that this increase in internal metabolism, driven by possible metabolic fat adaptation, may result in weight maintenance while calories obtained from fat consumption increase. However, this physiological adaptation should be viewed with a degree of scepticism as change from a baseline average could have come from an increased accuracy of food tracking over time. Measuring dietary intake through self-reported food tracking has been well-researched and comes with inevitable inaccuracies (Bingham et al., 1994; Illner et al., 2012). The advantage of using self-reported mobile- and computer-friendly food tracking over older methods (i.e., 24-hr diet recall), allows for frequent and efficient data collection and real-time assessment of food intake (Blake, 2008; Illner, et al., 2012). However, digitally recording food intake comes with its own inaccuracies (Freedman, Schatzkin, Midthune, & Kipnis, 2011) as under-reporting of food and portion sizes can still lead to inconsistent data collection. The specific application used in this current study, My Fitness Pal®, has its own user-driven database compiled from previous food entries, which researchers found to be frequently unreliable. Therefore, each participant's data was filtered through Food Works® to ensure accuracy in nutrient breakdown. Future research needs to closely monitor food intake either through giving participants food or developing a strict list of foods from which they can select.

Strength performance was either slightly increased or maintained after moderate to large changes to carbohydrate intake in four out of five participants' 1RM assessments. During competition preparation when weight reduction is a key goal for most weight-class restricted strength and power athletes, maintaining mainstream carbohydrate intakes for optimal performance may become difficult (G. Slater & S. M. Phillips, 2011). An *ad libitum* fat LCHF diet when carbohydrate is reduced (1.0 g.kg.day) that maintains competition performance and induces a small reduction in bodyweight could be an alternative strategy to other weight loss methods. During competition preparation for weightlifting sports, energy expenditure is low due to tapering (G. Slater & S. M. Phillips, 2011) and the sport has a high reliance on the ATP-CP energy system (Tesch, Thorsson, & Fujitsuka, 1989). Therefore, reliance of strength performance on carbohydrate intake may not be as pivotal as previously thought (G. Slater & S. M. Phillips, 2011). If the body is able to interchange between fuel sources and not become overly reliant on one fuel system, this is termed metabolic flexibility (Kelley, He, Menshikova, & Ritov, 2002). As intramuscular triglycerides increase through high fat consumption and skeletal muscle becomes more reliant on this substrate, glycogen depletion may be prevented from becoming too severe. If this is the case, participants could have been using fat during periods of rest while switching to available glycogen during periods of work. However we can only speculate as to the fuel utilisation changes that occurred during this study as this was not directly measured.

Conclusion and Practical Application

The results of this study indicate that an LCHF diet can be adhered to for an extended period of time without substantial deviations in strength and power performance and can result in a modest reduction in bodyweight and skinfolds. Therefore, the application of this diet could be a worthwhile and viable weight loss strategy for athletes who have difficulty with enforced calorie restriction and for those who are seeking safer practices to elicit weight loss. This study is only a small step towards understanding the effects and potential utility of LCHF diets for strength and power athletes. Further work needs to be undertaken, particularly relating to fuel utilisation during resistance training using the LCHF dietary approach.

CHAPTER 5 – The effect of an 8-week an LCHF diet on adherence and mental state in sub-elite Olympic weightlifters and powerlifters.

Abstract

Purpose: The effect of adapting to a low carbohydrate, high fat (LCHF) diet in strength and power athletes has been rarely investigated qualitatively. The purpose of this study was to examine adherence to and acceptability of an 8-week LCHF intervention in sub-elite level Olympic weightlifters and powerlifters (n=8). **Methods:** The Daily Analysis of Life Demands for Athletes (DALDA) was recorded across a 16-week study period (4-week baseline, 8-week LCHF intervention, 4-week post-intervention period). In addition, a one-on-one interview was conducted during the last week of the 8-week LCHF dietary intervention, followed by a post-study online questionnaire. Regression analysis was used to identify any significant linear or non-linear trends that emerged between the DALDA data and weekly training sessions. Qualitative measures were thematically analysed to classify categories and themes emerging from post-diet one-on-one interviews and the post-study questionnaire. **Results:** From the DALDA analysis, statistically significant trends ($p>0.05$) were found in multiple participants for "tiredness" and "need for rest" with a greater prevalence of 'worse than normal' scores during the LCHF diet intervention. Tiredness and need for rest were compared against each training week and were each classified as either high, medium, or low volume. In addition, some participants commented during interviews about having low energy levels and fatigue during the initial weeks of the LCHF diet intervention. However, overall all the participants found the diet to be acceptable in terms of their training and lifestyle. **Conclusion**: Participants who began the LCHF intervention were able to successfully adhere to an 8-week LCHF diet.

However, higher training volumes may elicit greater tiredness and a need for longer recovery periods while consuming an LCHF diet. Nevertheless, future research should continue to investigate the application of an LCHF diet for weight loss leading up to competition for weight-restricted strength and power athletes due to the promising findings of the current study.

Key words: low carbohydrate high fat diet; adherence; acceptability; DALDA; Olympic weightlifting; power lifting

Introduction:

Increasing relative strength performance is pivotal for athletes involved in weight-class restricted sports such as Olympic weightlifting and powerlifting. However, some approaches to weight loss used by these athletes may not allow for maintenance of optimal performance leading into a competition (Garthe, et al., 2011). Rapid weight loss methods such as dehydration strategies or severe calorie restriction allow for weight loss but can be detrimental to performance (Brownell, Steen, & Wilmore, 1987). A low carbohydrate high fat (LCHF) diet could provide an alternative method for weight loss during competition preparation, which may help maintain performance during body weight reduction (Paoli, et al., 2012; Sawyer, et al., 2013b). However, an important aspect missing from the current LCHF literature is qualitative information regarding the acceptability of an LCHF diet for strength and power athletes. Such information would help to inform the prescription and practice of LCHF diets, as adherence and diet acceptability are considered two of the most important factors for sustained weight loss (Dansinger, Gleason, Griffith, Selker, & Schaefer, 2005).

Current research has indicated that simultaneous carbohydrate and calorie restriction can cause higher depression and fatigue levels if energy intake is substantially limited (Helms, Zinn, Rowlands, Naidoo, et al., 2014; Horswill, et al., 1990). Additionally, a low calorie low carbohydrate diet can cause a reduction in strength and power performance (Helms, Zinn, Rowlands, Naidoo, et al., 2014; Horswill, et al., 1990; Walberg, et al., 1988). Alternatively, an LCHF diet that allows for the consumption of fat and/or protein *ad libitum* may induce a spontaneous calorie reduction, causing a small reduction in body fat combined with water-weight loss associated with carbohydrate restriction (Bergström, et al., 1967), which may adequately reduce bodyweight while strength and power performance is maintained (Paoli, et al., 2012; Sawyer, et al., 2013b).

However, there is very little qualitative information regarding the experience of athletes who have followed LCHF diets. Only a small qualitative note from Paoli et al. (2012) identified that some participants found it too challenging to complete training during the first week of a ketogenic diet (<50g of carbohydrate, ~120g of fat and ~ 200g of protein per day), but that these feelings subsided after that point. Klement et al. (2013) used a descriptive analysis in which physically active participants, who underwent 40 days of a ketogenic diet, were given a short questionnaire to document their subjective experience during the diet. In this study, it took participants two to three weeks to get through the initial adaptation period before recovery and energy levels returned to normal. Interestingly, throughout the ketogenic diet, a common trend most participants described was the inability to recover quickly from high-intensity exercise. These results provide some insight into the feasibility of a self-directed ketogenic diet on strength and power performance. However, more qualitative information is needed to gain further insight into the acceptability of non-calorie controlled LCHF diets for strength and power athletes.

Therefore, this study set out to understand the changes in mood and perception in Olympic weightlifters and unequipped powerlifters during a non-calorie restricted LCHF diet through the completion of online Daily Analysis of Life Demands for Athletes (DALDA) forms, a one-on-one interview and a post-study questionnaire. Additional quantitative data was collected during this study. Anthropometry, strength and power performance are detailed in Chapter 4. To avoid repetition, readers will be referred to Chapter 4 at various points in the following methods and results sections.

Methods

Participant characteristics and general study design:

For a description of the participants and the general testing procedure, please refer to Chapter 4. Figure 2 highlights the study structure previously described in Chapter 4.

Phase		Retrospective and baseline data				LCHF Dietary Intervention								Post Invention				
Weeks	Pre	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Post
	↑				↑				↑				↑					↑
Tests	C1				C2				C3				C4, IV					C5, PQ
		Daily completion of DALDA and self-reported dietary intake																

Figure 2: Schematic of testing procedures over the 16-week case study.

Pre; pre-study; C1,2,3,4,5: consultation with participant; Interview; one-on-one interview; PQ: Post intervention questionnaire; Post: post-study

Note: Dietary monitoring data was collected and examined each week throughout the whole 16-week study period.

DALDA questionnaire:

The DALDA questionnaire (Appendix 7) was used to evaluate stress levels of the athletes throughout the entire study (Rushall, 1990). DALDA forms were made available to all participants through an online survey website (Survey Monkey®). The DALDA questionnaire is split into components: Part A contains 9 questions related to sources of stress; Part B contains 25 questions relating to signs and symptoms of stress (Rushall, 1990). For each question in both sections, participants had three answer options; A) ‘Worse than normal’, B) ‘Normal’ or C) ‘Better than normal’. Participants were advised to complete Part A before Part B. The DALDA form was required to be completed at a similar time each day during the study. Data were extracted from the online survey website and inserted into an Excel spreadsheet. Data were collated into a point system with -1 = ‘Worse than normal’, 0=“Normal” and 1=‘Better than normal. A numeric weekly mean score for each question from both Part A and Part B was then calculated in addition to a total weekly mean score for all questions in Part A and Part B. The weekly data were then plotted and analysed using regression analysis to identify any significant linear or non-linear trends. In addition, each weekly mean DALDA question during the LCHF intervention was given a classification and colour coded with either high stress (red), medium stress (blue) or low stress (green). This was calculated by taking the largest and smallest stress averages recorded during the 8-week LCHF intervention to provide a range. If participants missed days due to scheduling conflicts or periods where they were without internet access, participants were required to backdate entries to allow for a minimum of three entries per week to formulate a weekly average.

Training Volume:

Each participant was required to track and send the researchers a weekly record of training from which total weekly training volume (calculated in kg as sets multiplied by reps multiplied by load) was recorded. To evaluate changes to training volume during the LCHF intervention phase, a mean baseline training volume was calculated from the 4-week baseline period that occurred immediately prior to the LCHF intervention. Following this, each week of the LCHF intervention was compared back to the mean baseline training volume. High, medium and low training volume categories were calculated by taking the largest and smallest total volume performed during the LCHF intervention to provide a range over the 8 weeks. Training volumes were then colour coded to allow a comparison to be made between each training phase and the corresponding participant stress response (DALDA questionnaire data): high training volume (red); medium training volume (blue); or a low training volume (green).

Interview and post-study questionnaire:

Each participant was interviewed separately for up to 30 minutes during the final week of the 8-week LCHF intervention. These interviews were designed using open-ended questions to achieve maximum collection of qualitative information regarding participants' physical, mental and social experience during the diet (Table 8). These interviews were collected using a recording device and the information was then transcribed and analysed using a thematic analysis process. In addition, a post-study questionnaire was emailed to participants with questions directed towards their overall experience including their return to the post-intervention dietary phase (Table 9). Transcripts were reviewed several times to obtain emerging major themes and all data relating to these themes were selected from the transcripts (Gavin, 2008). Sub-themes were then drawn out within the major themes for a more detailed insight into the data. This was then cross-referenced with the original transcript to ensure the accuracy of the sub-themes.

Table 9: One-on-one interview questions

Diet perspective pre LCHF diet
- Describe your initial perspective of a low carbohydrate high fat diet

Diet perspective post LCHF diet
- Describe your new perspective of a low carbohydrate high fat diet

Experience of a typical training day during
- Describe how you felt prior to training while on this diet
- Can you describe the differences in your energy levels or mood from your habitual diet prior to training?
- Describe how you would typically feel during training while on this diet
- Describe how different training days (high volume or high intensity) while on the LCHF diet affected you compared to your habitual diet
- Describe your recovery after training and whether that changed during the LCHF diet.

Socialising and lifestyle while LCHF dieting
- Describe how you found eating outside of home and your social experiences while eating an LCHF diet
- How did you felt about the foods you were able to eat during the diet?
- Did you feel like you had to go out of your way or change your behaviour during social events?

Satiety of LCHF diet
- Describe any differences in your feeling of fullness during the LCHF diet compared to your normal diet
- How did your satiety levels change throughout the 8 weeks?

Table 10: Post-study questions

- How have you found your transition out of the LCHF diet?
- How has your diet changed from your original diet after your experience with reducing carbohydrate?
- Describe the quality of your training sessions after completing the LCHF diet
- Has the recovery from and experience during training improved, stayed the same, or become worse?
- Can you describe your overall energy levels over the past four weeks?
- Have you felt weaker, stronger or about the same over this period?
- Have you gained or lost any weight since you have come off the diet?
- Can you describe the quality of your sleep over the course of the dietary intervention? Have you noticed any differences in your sleeping patterns since you have transitioned from the LCHF diet?
- How has your mood been affected over the past four weeks while returning back to your normal diet?
- If you were trying to lose weight for competition, would you use the same approach again that we used in this study?
    - If yes, would you have kept it the same or altered it?
    - If no, what would your approach be?

Data Analysis

Firstly, pre- to post-intervention change scores were expressed as percentage changes for each individual. In addition, regression was used to identify any significant linear or non-linear trends that emerged between the DALDA data and weekly training sessions. All analyses were conducted using SPSS (IBM® SPSS® Statistics, version 20) using an alpha of $p < 0.05$.

Thematic analysis was used to analyse and classify categories and themes emerging from both the one-on-one interviews and the post-intervention questionnaire. The recordings of the one-on-one interviews were transcribed and coded into relevant themes. Themes were presented alongside supporting transcripts to convey interpretations of data.

Results

Data representing dietary intake, 1RM testing, anthropometry and ultrasound are presented in Chapter 4.

DALDA and Training Volume:

'Tiredness' and 'need for rest' were the only questions from the DALDA questionnaire that had statistically significant similarities in curve trends ($p<0.02$) among participants. Participant 1 ($p<0.02$) and Participant 5's ($p<0.02$) 'tiredness' increased during LCHF W1 to W2 followed by a return to baseline levels (Table 10). See Appendix 9 for figures for Participants 1 and 5's significant trends over the study. Participants 2, 3 and 4 showed no trend in tiredness over the 16-week study period.

There were non-linear trends in 'need for rest' for Participants 1, 2 and 3 (Table 11). See Appendix 10 for figures for Participants 1, 2 and 3. Participant 1 responded with a decrease in 'need for rest' from LCHF W1 to LCHF W4, while training volume was predominantly moderate to high. This was followed by an increase in 'need for rest' as training volume decreased to low. Conversely, Participant 2's 'need for rest' increased from LCHF W1 to LCHF W4, followed by a decrease in 'need for rest' from LCHF W5 to LCHF W7. Participant 2 suffered a right shoulder injury during LCHF W7. Training volume did not appear to have a relationship with changes to 'need for rest'. Participant 3 reported an increase in 'need for rest' from LCHF W1 to LCHF W5, which then regressed back to baseline average in LCHF W6 and LCHF W8. This coincided with moderate and low training volume during LCHF W7 and W8 respectively. Participants 4 and 5 had no trends associated with need for rest.

Table 11: Change in weekly total volume (in kg) and percentage of change (%) of mean baseline with DALDA weekly mean 'tiredness' scores during 8-week LCHF intervention.

Participant	Variable	Baseline Mean	LCHF W1	LCHF W2	LCHF W3	LCHF W4	LCHF W5	LCHF W6	LCHF W7	LCHF W8
1	Training volume	24141	36519 (+51.30%)	30775 (+27.5%)	44956 (+86.2%)	30906 (+28.0%)	16875 (-30.1%)	17304 (-28.3%)	6780 (-71.9%)	7720 (-68.0%)
	Tiredness*	-0.481	-0.143	-0.167	0.167	-0.286	-0.500	-0.143	-0.400	-0.750
2	Training volume	20522	6160 (-69.9%)	23226 (+13.2%)	17105 (-16.6%)	13747.5 (-33.0%)	5629 (-72.6%)	17615 (-14.2%)	22550 (+9.9%)	20365 (-0.8%)
	Tiredness$^{(p<0.06)}$	-0.525	-1.000	-1.000	-1.000	-1.000	-0.667	-0.333	-0.800	-0.833
3	Training volume	20666	20060 (-2.9%)	25620 (+24.0%)	19802 (-4.2%)	24523 (+18.7%)	21752 (+5.3%)	27560 (+33.4%)	20060 (-2.9%)	14562 (-29.5%)
	Tiredness	-0.143	0.000	-0.143	0.000	-0.290	-0.500	-0.143	-0.429	0
4	Training volume	31638	32910 (+4.0%)	26020 (-17.8%)	33240 (+5.1%)	23768 (-24.9%)	25875 (-18.2%)	11058 (-65.1%)	31815 (+0.6%)	29235 (-7.6%)
	Tiredness	-0.364	-0.429	-0.167	0.143	-0.167	0.000	0.000	-0.143	-0.333
5	Training volume	46196	40025 (-13.4%)	42725 (-7.5%)	43085 (-6.7%)	20422 (-55.8%)	40975 (-11.3%)	14450 (-68.7%)	22292 (-51.7%)	34329 (-25.7%)
	Tiredness*	-0.113	-0.250	-0.286	0.000	-0.286	-0.600	-0.500	-0.286	0.000

Note: Red: High volume/high stress, Blue: Medium volume/medium stress, Green: Low volume/low stress *Significant trend of $p<0.05$

Table 12: Change in weekly total volume (in kg) and percentage of change (%) of mean baseline with DALDA weekly mean 'need for rest' scores during 8-week LCHF intervention.

Participant	Variable	Baseline mean	LCHF W1	LCHF W2	LCHF W3	LCHF W4	LCHF W5	LCHF W6	LCHF W7	LCHF W8
1	Training volume	24141	36519.5 (-51.30%)	30775 (-27.5%)	44956 (-86.2%)	30906 (-28.0%)	16875 (-30.1%)	17304 (-28.3%)	6780 (-71.9%)	7720 (-68.0%)
	Need for rest*	-0.458	0.000	0.000	0.286	0.000	-0.167	0.143	-0.2	-0.25
2	Training volume	20522	6160 (-69.9%)	23226 (-13.2%)	17105 (-16.6%)	13747.5 (-33.0%)	5629 (-72.6%)	17615 (-14.2%)	22550 (-9.9%)	20365 (-0.8%)
	Need for rest*	-0.297*	-1.000	-1.000	-1.000	-0.333	-0.500	-0.167	-0.200	-0.667
3	Training volume	20666	20060 (-2.9%)	25620 (-24.0%)	19802 (-4.2%)	24523 (+18.7%)	21752 (-5.3%)	27560 (-33.4%)	20060 (-2.9%)	14562 (-29.5%)
	Need for rest**	-0.012	-0.286	-0.143	0.000	-0.430	-0.500	-0.290	-0.286	0.000
4	Training volume	31638	32910 (-4.00%)	26020 (-17.8%)	33240 (-5.1%)	23768 (-24.9%)	25875 (-18.2%)	11058.5 (-65.1%)	31815 (-0.6%)	29235 (-7.6%)
	Need for rest	0	0.143	0.167	0.143	0.000	0.000	0.000	0.000	0.000
5	Training volume	46196	40025 (-13.4%)	42725 (-7.5%)	43085 (-6.7%)	20422.5 (-55.8%)	40975 (-11.3%)	14450 (-68.7%)	22292.5 (-51.7%)	34329 (-25.7%)
	Need for rest	-0.113	-0.250	-0.286	0.000	0.000	-0.400	-0.500	-0.286	0.000

Note: Red: High volume/high stress, Blue: Medium volume/medium stress, Green: Low volume/low stress *Significant trend of $p<0.05$, ** Significant trend of $p<0.01$

One-on-one interview:

Five separate one-on-one interviews were carried out during the last week of the 8-week LCHF diet intervention. Similar themes across the five participants were identified in all interviews. Table 4 summarises the key themes from each of the participants' interviews. A central theme of positive diet acceptability with respect to the LCHF diet intervention was drawn out of interview transcripts. Five sub-themes within this major theme were: 1) fear associated with eating an LCHF diet; 2) surprise with their experience; 3) initial training fatigue; 4) initial satiety; and 5) changes in mood.

The first theme was a fear associated with lowering carbohydrate and increasing fat. Collectively participants felt as if they were going to be restricted in training as well as having to consume a lot of fat in their diet.

> "*I thought it was pretty gross to be honest, I hold quite an old school mentality that fat is bad…"* (Participant 4)

Participants were generally surprised with their experience of the LCHF diet. The fear subsided and participants were able to adapt comfortably. All five participants who began the diet were able finish with minimal difficulty as depicted by the quote below;

> "*After going through the diet it was more sustainable than I thought. Once my cravings went after about 5 weeks it was ok*." (Participant 3)

The initial 'adaptation period' of the diet involved fatigue. All participants at some point experienced weakness or low energy during the 8-week period. Participants 1, 3 and 4 had low energy and reported feeling weak occasionally during the initial four weeks of the diet. However, after this point these negative feelings diminished and returned to normal. Participants 2 and 5 had varying bouts of fatigue during the 8-week intervention. In addition, some participants reported they needed longer recovery times during high volume training weeks.

> "*When I first started I had a lot less energy and I felt fatigued all the time at training and there were times after every single rep I would get dizzy to the point of almost passing out*." (Participant 4)

> "*I couldn't go as many sets. I just had to go with it and do what I could and just push past it otherwise I would have got more run down*" (Participant 1)

In addition to fatigue, satiety of the diet was a strong theme featured in the interviews. The feeling of fullness was associated with the high amount of fat consumed. Participants commented on finding it hard to finish meals, which was not regularly reported to be a problem when consuming their habitual diet. Participants 2, 4 and 5, who were more accustomed to dieting, described instances where they were surprised at how little they needed to eat to stay full. It was described by Participant 5 as "dieting without actually dieting".

> "*I was very satiated during the first three or four weeks and I was surprised how much I was dropping my calories as I was trying to eat to fullness as I would normally do*" (Participant 5)

Lastly, changes to mood, feelings of being restricted to certain foods, and social barriers were identified as a theme related to the LCHF diet. As the diet continued, the novelty of LCHF dieting wore off and frustrations around the types of food the participants could consume, as well as frustration during social outings where food was central, began to increase. For example, Participant 5 felt that LCHF dieting was a barrier in their social life and expressed feeling restricted in the types of foods available. In addition, Participants 4 and 5 noticed changes to their daily mood and they became more irritable and quicker to anger while on the LCHF diet.

> "*It is not a huge change it's a subtle one but I have noticed that I have been spending more time slightly annoyed*." (Participant 5)

Post-study questionnaire:

Each participant completed a post-study questionnaire that comprised questions relating to diet acceptability, experience of re-entry into their baseline diet and how they would modify the diet for personal use.

1. Diet acceptability

Overall participants reported that they enjoyed their dieting experience. Participants 3 and 4 added foods, such as cream and coconut oil, that they enjoyed from the diet into their post-intervention diets. No negative attitudes to the LCHF intervention were expressed by participants.

2. Diet re-entry

Participants who were fatigued on the LCHF diet found their energy levels were able to stabilise quicker and they had more consistency in their training during the post-intervention phase. Participants (3, 4 and

5) who consumed more carbohydrate during the baseline phase, appreciated the post-intervention phase more than those participants (1 and 2) who consumed less carbohydrate during the baseline phase.

3. Diet Modification

Each participant had an idea of how this diet could be modified to help them perform optimally. Participants 3 and 5 suggested creating a cyclic pattern with their carbohydrate intake to avoid low energy days. Participant 5 based this on how they would logically prescribe the diet for themselves based on energy needs. Participant 3 said they would use high carbohydrate intakes during larger training volume periods to counteract fatigue, which occurred during the LCHF intervention. Participants 1 and 2 suggested they would reduce their carbohydrate further to elicit more weight loss. Lastly, Participant 4 stated they would adjust both carbohydrate and fat for optimal performance and keep at a lower body weight year-round.

Table 13: Themes from interviews with supporting transcripts

Fear associated with an LCHF diet
“I guess I would feel a bit weaker, and went into the diet with the expectation to lose a little bit of weight.” (Participant 1)
“My initial thoughts were, am I going to have enough energy to do everything because I the reloads (over carbohydrate) that I am so used to” (Participant 3)
“I thought diet was going to be a good one originally because I have heard a lot about it, especially in the last couple of years it been brought more to light…” (Participant 5)

Surprised with their experience
“Well since my skinfolds were going down it was good but I would definitely suggest the meal planning” (Participant 2)
“After going through the diet it was more sustainable than I thought. Once my cravings went after about 5 weeks it was ok.” (Participant 3)
“My training is sweet. I feel like my training energy levels are now similar to what they used to be when I was not on the diet and did not have to rest for longer periods.” (Participant 4)
“I would say for the first four weeks it was, it was doing something cool and different” (Participant 5)
“I was surprised how little I was affected with going so low carb, in terms of training which a good thing, in my mind was that it allowed to me see that I had more flexibility in a way I set up my macronutrients without having a negative impact in performance.” (Participant 5)

Initial training fatigue
“I felt during the first week or two I was a bit sluggish but felt pretty good after that” (Participant 1)
“There was one particular training where I think I was getting into it and I was like I can’t lift these weights why can’t I lift these weights and just was not happening” (Participant 2)
“I had some dizzy spells in the first week and thought I was going to pass out which levelled out and did not happen as commonly. I also had the odd headache but once I sorted out my electrolytes this sorted it out.” (Participant 3)

Initial satiety
“Yes my hunger changed. Well at the beginning I was not hunger because of the protein and all that but now it has gone back to” (Participant 2)
“The first half of it, I remember not being able to finish a meal. We had put together the curry with coconut milk and I could not finish it, I just felt so full. And now I am a lot hungrier a lot more of the time. I find myself eating faster” (Participant 4)
“I was very satiated during the first three or four weeks and I was surprised how much I was dropping my calories as I was trying to eat to fullness as I would normally do” (Participant 5)
“…right around week four and now I have been more food focused than I was previously so I would get hungry at a certain point and aware of food and trying to think about what I am going to eat” (Participant 5)

Changes in mood
“That is something that I have noticed is that I have been more irritable on this diet” (Participant 5)
“…but it was more of a psychological restriction, social restriction would be the best way to put it.”(Participant 5)
“… I was more susceptible to getting angry was heightened, like a lot. Small things that used to never bother me, just like pushed me over edge. I think I was more fragile” (Participant 4)

Discussion

All participants were able to adhere to the 8-week LCHF diet. Trends were seen predominantly in the 'tiredness' and 'need for rest' DALDA items among participants in the first four weeks of the LCHF intervention. This coincided with responses during one-on-one interviews that revealed 'initial fatigue' as a key theme during the LCHF intervention. Although each participant found the LCHF diet acceptable in terms of their training and lifestyle, they did recommend that the LCHF diet would be better suited to themselves if it was modified to their preferences, either implemented in a cyclic fashion throughout a training season or reducing carbohydrate to ketogenic ranges (<50g of carbohydrate per day). DALDA responses and training volume appeared to have a relationship, where high volumes of training increased the stress response. Therefore, the effects of an LCHF diet on changes to mood and stress may have been masked by different training phases.

No current research has yet investigated LCHF diet acceptability qualitatively in dieting athletic populations. However, it is well known that an LCHF diet can be successfully adhered to for up to 12 months in overweight populations (Stern et al., 2004), and may be an alternative for individuals who struggle to adhere to traditional calorie-restricted diets (Shai et al., 2008). As adherence to a diet is considered one of the most important variables for sustained weight loss (Dansinger, et al., 2005), the results of this investigation have shown that an LCHF diet can be successfully applied to competitive strength and power athletes. Overall there was a general acceptance of the LCHF diet, as participants commented on overcoming initial fears surrounding dramatic increases in dietary fat consumption. In addition, the participants were generally surprised with the relatively small effects the diet had on their performance and lifestyle. Factors contributing to the success of adherence may have included the support system provided by the researchers during the LCHF intervention and the participants' own personal predisposition to an LCHF diet. Participants who volunteered for this study may have held a predisposition favouring LCHF diets prior to their participation. In addition, each participant was provided with basic food (i.e. coconut oil, nuts and canned tuna) and a guidebook to LCHF eating (see Appendix 8) along with constant support. Each of these factors may have provided extra motivation to complete the diet.

During the interviews, three out of five participants stated that they experienced an increase in fatigue and tiredness during the initial 1 to 2 weeks of the LCHF intervention. However, this was not reflected in trends reported in their DALDA questionnaire entries. A major contributor to fatigue could have been the interaction between high training volume and the restriction of carbohydrate (L. M. Burke, et al., 2011). Interviews revealed that there is a possibility that a higher training volume could have been more difficult during carbohydrate restriction, in particular during the initial weeks of diet adaptation. However, this was not reflected entirely in the DALDA responses. A limitation of this study was missing DALDA data, as some participants were unable to complete their online entries due to travel or busy schedules. The missing data points may have masked more prominent changes to stress levels. The variability of different training volumes could also have affected the signs and symptoms of stress among participants, as DALDA stress responses are highly sensitive to training volume changes (Halson et al., 2002; Storey, et al., 2015). For example, Halson et al. (2002) reported an increase in 'worse than normal' responses associated with fatigue during an intensive (high volume) 2-week training block. Similarly, researchers in a recent study reported that a 2-week intensified training period (i.e. an increase of 12-15% in training load) in international-level weightlifters coincided with a significant increase in negative mood state along with an increase in the signs and symptoms associated with stress (Storey, et al., 2015). In this current study, three factors that influenced higher responses for tiredness and need for rest were: i) periods of high volume training (Participant 5); ii) periods of high intensity training with low volume (Participant 1); or iii) during the initial 4-week 'adaptation period' of the LCHF intervention (Participant 3). This initial four weeks of the LCHF diet have been previously observed as a period of adaptation that is frequently discussed in ketogenic diet research (Volek & Phinney, 2012). These symptoms are expected as the body undergoes metabolic changes to become more efficient at metabolising fat (Lambert, et al., 1997). This re-orchestration of the body's metabolism can take some time. The process of fat adaptation causes the body to continue to rely on glycogen stores under glycogen depletion before progressive enzymatic changes allow for more efficient fat utilisation (Lambert, et al., 1997). For example, Participant 5 had their highest bout of training volume spanning the baseline period and the first four weeks of the LCHF intervention phase, leading to an increase in tiredness. Once training volume decreased, Participant 5's stress levels were able to return back to baseline following a cubic trend ($p<0.02$).

Previous research has suggested individuals consuming a ketogenic diet may experience fatigue during the initial weeks (Klement, et al., 2013; Paoli, et al., 2012). In addition, some participants in this current study noted that high fat consumption may have a stigma of being bad for health as an LCHF diet is often viewed as contrary to conventional dietary recommendations. Both themes were common among participants, particularly those who were consuming the highest carbohydrate intake during the baseline period (Participants 3-5). During severe carbohydrate restriction (i.e ketogenic diets), this initial fatigue period is often referred to in the literature as 'keto-flu' as the body metabolically regulates itself to use fat as fuel (J. Volek & Phinney, 2012). To a lesser extent in this current study, participants may have experienced a similar metabolic adaptation response to accommodate for a reduction in carbohydrate. Participant 3 had dizzy spells during his training session during the first week of the LCHF intervention and was advised by our Registered Dietician to increase his electrolyte intake, particularly of sodium. This strategy is commonly used for individuals undergoing severe carbohydrate restriction (J. Volek & Phinney, 2012) and was sufficient to alleviate Participant 3's symptoms of dizziness. In addition, Participants 2 and 3 decreased their training volume during week 1 of the LCHF intervention, possibly to accommodate for the dietary change. Though participants experienced some difficulty during the initial phases of the diet, an adjustment of electrolytes or a decrease in training volume was used by participants to limit these side effects. Unfortunately, as training was altered by Participants 2 and 3, this may have masked any negative effects that the LCHF diet had on their training. As training volume varied between participants, it is unknown whether these participants would have been able to complete a standardised training program where standardised volumes and intensities were prescribed and closely monitored. In addition, while performance did not decrease in the majority of participants, no improvements outside of their general trend of improvement over time occurred during the LCHF diet either (data shown in Chapter 4).

Initial enhanced satiety was reported often during the interviews, as some participants were unable to finish meals and had a reduced sensation of hunger (dietary intake data is presented in Chapter 4). A notable reduction in calorie intake was observed in 4 out of 5 participants. Protein intake was held constant, making fat intake the only macronutrient that increased during the intervention. Thus, the perception of fullness was most likely due to an increase in cholecystokinin (CCK) secretion that arises after fat consumption. Similarly, past research has found an increase in CCK causes a delay in gastric emptying and an increase in gastric filling which results in an increased perception of fullness and a decrease in hunger (De Graaf, et al., 2004; Melton, Kissileff, & Pi-Sunyer, 1992). Mainstream weight-loss diets, where calories are purposely restricted and fat intake is typically low, tend to increase hunger and create the desire to eat more (Doucet et al., 2000). In contrast, LCHF eating can be described by one participant's comment, 'it is a way to diet without feeling like you are dieting'. Similarly, some participants commented on the reduction of cravings throughout the day that they typically experienced on their habitual diet. Beyond the aforementioned physiological changes, the satiety produced by the LCHF diet could have further enhanced adherence to the LCHF diet.

Participants 4 and 5 both reported a slight increase in irritability and ill-temper during the one-on-one interviews. However, this was not represented by significant trends in their DALDA questionnaire entries. Only Participant 5 showed a non-significant ($p<0.09$) trend of improved temper during the 'return to normal' phase. This change to mood could be due to the length of the intervention period, as limited food choices may have become monotonous to participants (Hetherington, Pirie, & Nabb, 2002; Johnstone, Horgan, Murison, Bremner, & Lobley, 2008). Opposing this finding, Participant 2 reported improved DALDA irritability scores ($p<0.01$) while consuming the LCHF diet before suffering a right shoulder injury during the 6th week of the intervention phase. While individual differences varied, in general changes to mood during the LCHF intervention were minor.

Ultimately, an athlete's compliance with competition preparation is the key to success in any weight-loss period, regardless of method. Participants' comments from the post study questionnaire provided an opportunity to understand athletes' perspectives on how they would modify an LCHF diet in the future to accommodate a more successful competition preparation. Participants 1 and 2 suggested a need for a greater reduction in carbohydrate in order to lose weight. Additionally, they experienced a reduction in the stress responses for ‘Need for rest’ (Participant 1, $p<0.02$), ‘Tiredness’ (Participant 1) and ‘Diet’ (Participant 2) during the LCHF intervention. The combination of limited weight loss (see Chapter 4) while experiencing a decrease in stress during the LCHF intervention may indicate that these participants could have tolerated and perhaps benefitted from a greater carbohydrate reduction to decrease weight further.

Conclusion and future research:

An 8-week LCHF diet appears to be mostly acceptable for the training and lifestyle of sub-elite Olympic weightlifters and unequipped power lifters. Participants did experience tiredness during the initial weeks, which subsided after approximately 4 weeks of LCHF dieting. In addition, there was evidence of stress related to social and food restrictions among some participants. When choosing an appropriate diet for athletes who seek to lose weight whilst maintaining and/or improving performance, it is important to consider their individual needs and preferences. This is due to individual variability in response to different diets (Helms, Aragon, & Fitschen, 2014). As discussed by Helms et al. (2014), a variety of factors, such as genetics, muscle fibre composition and age, may influence how receptive an individual is to any form of diet. This current study is a testament to individual variability as participants had a similar LCHF diet, yet each had a unique personal experience. The variability in each participant’s training volume may have masked the stress of the LCHF diet, and this was evident in the amount of variability between individual DALDA responses throughout the study. Nevertheless, information communicated by some participants drew similarities with their response to the LCHF diet. In addition, several participants expressed the possible need to cycle high and low carbohydrate intakes systematically throughout different phases of training, which is a contemporary topic in sports nutrition and may have potential for optimising strength and power performance. Further research needs to target how an LCHF diet could be cycled throughout a training year to avoid the monotony of dieting and to accommodate varying training volumes.

CHAPTER 6: Discussion and future research

Preface

This chapter considers the findings in Chapters 4 and 5 in conjunction with current literature to highlight key findings and discusses potential areas for future research. An initial review of the relevant literature in Chapters 2 and 3 provided an extensive background to the application of an LCHF diet in sport nutrition with a particular emphasis on strength and power athletes. In addition, these chapters highlighted areas that required further research, which directed the purpose of this thesis. The results presented in Chapters 4 and 5 were novel concepts that have not been previously observed and provide a framework for more robust study designs for future research.

Discussion

The efficacy and the value of LCHF dietary application in strength and power athletes are not fully understood. Previous research has shown that weight-restricted strength and power athletes can lose weight using a variety of different methods (Artioli, et al., 2010; Brownell, et al., 1987). However, the effects on strength and power performance or on the psychology on the athlete during their weight loss journey are rarely considered. The findings of this thesis demonstrated that a non-calorie controlled LCHF diet is an effective way for an athlete to achieve their weight-loss goals while maintaining strength, performance and mental health. In contrast to typical weight loss diets where a calorie deficit is prescribed, the satiating nature of an increased consumption of fat or the satiety combination of both fat and protein during an LCHF diet may cause a spontaneous calorie reduction (Paoli, et al., 2012; Sawyer, et al., 2013b). In support of previous investigations, the results of our research indicated that participants were able to spontaneously reduce their calorie intake. Despite the limited research addressing this issue, it appears that the spontaneous calorie reduction during an LCHF diet has no direct negative effect on strength and power performance. During our research, participants began to slowly and spontaneously increase calorie consumption after the first two weeks of the LCHF diet intervention towards similar habitual diet levels. It is possible that this increased calorie consumption is associated with a decrease in satiety signalling, primarily via a decrease in leptin, during body weight reduction (Morton, et al., 2006). Nonetheless, whether or not a spontaneous calorie decrease or increase is induced only by changes in satiety signalling warrants closer investigation.

Changes to calorie consumption may not be entirely due to physiological changes: dietary self-reported error and familiarisation to a diet may have contributed to this effect seen in the current study. Each participant self-monitored and recorded their daily food intake, which relied on the accuracy of participants measuring their food portions. While they did receive thorough advice on how to accurately measure and record intake, they were not physically monitored during this process, for practical reasons. In addition, an initial mental barrier that participants may have faced could have been a feeling of limited food choices. Participants may have initially felt limited by the restriction of high carbohydrate foods, i.e., grains, which previously could have been a staple of their baseline diet. However, the provision of an extensive LCHF handbook (Appendix 7) aimed to minimise the feeling of food restriction. After this initial period, a more prolonged familiarisation with different LCHF foods or the return of hunger may have resulted in the progressive increase in the amount of calories consumed, which rose to the original baseline consumption. Also, the realisation that participants could continue to eat more fat while losing bodyweight may have prompted them to continually increase calorie intake. Interestingly, this increase in calorie consumption was a novel finding that has not been reported in previous non-calorie controlled LCHF research (Paoli, et al., 2012; Sawyer, et al., 2013b) . Therefore in summary, satiety, adapting to limited food choices, or both may have resulted in an initial decrease (3-33%) followed by an increase in calories consumed by most participants when compared to their baseline consumption.

What was most interesting to us was that the increase in calorie consumption during the LCHF intervention did not result in weight regain, and the initial loss in body weight (whether it was derived from body water and / or fat mass) was maintained. A potential mechanism for body weight maintenance may be a greater efficiency in utilising free fatty acids for fuel, which may also drive a greater internal metabolism within the body. Similarly, previous research investigated overeating and its effect on energy expenditure through non-exercise thermogenesis (Leibel, Rosenbaum, & Hirsch, 1995; Levine, Eberhardt, & Jensen, 1999). Interestingly, postprandial (post-meal) thermogenesis through metabolising a meal can result in an increase in energy expenditure of up to 14% during overfeeding (Levine, et al., 1999). Therefore, increasing calorie consumption could also increase resting metabolism, causing a resistance to body fat and weight gain (Levine, et al., 1999). In addition, a low carbohydrate diet has been reported to induce a greater increase in resting energy expenditure (67 kcal.day) than a low fat diet (Ebbeling et al., 2012). This is only speculation about why participants in the present study did not gain weight, as energy expenditure was not measured, but is an intriguing finding and is well worth deeper investigation using energy expenditure methods.

The results from this study and from others (Mitchell & DiLauro, 1997; Paoli, et al., 2012; Sawyer, et al., 2013b) suggest that strength and power performance can be maintained over a period of LCHF dieting. However, this is in a diet regime where calories are not restricted, as the combination of both carbohydrate and calorie (~50% of habitual consumption) restriction can cause difficulty in fulfilling the energy demands of high intensity exercise (Walberg, et al., 1988). Previous studies have shown the energy demands of strength and power performance can be met through *ad libitum* (Paoli, et al., 2012; Sawyer, et al., 2013b) or sustained (Mitchell & DiLauro, 1997) calorie consumption while carbohydrate is restricted. This investigation supports those findings, as performance was neither negatively nor positively affected by carbohydrate restriction of around 1.0g.kg.day in the majority of participants. It appears that a strength and power athlete can be safely prescribed lower recommendations of carbohydrate, which have been previously established (G. Slater & S. Phillips, 2011), without detrimental effects on performance. However, it should be considered that some participants modified their training volume during the LCHF intervention, which may have led to a lack of positive performance changes. Therefore, future research should standardise each participant's training programme to limit individual training variability.

In addition to objective data collected, two methods of evaluating psychological factors were applied; one quantitative (DALDA questionnaire) and one qualitative (one-on-one interviews). The DALDA questionnaire and one-on-one interviews were used to provide detailed insight into each stage of adaptation to an LCHF diet, changes in mood and the psychological impact on lifestyle and training. The qualitative evidence gathered in this study indicated that beyond an initial adaptation period (1-4 weeks) where fatigue was higher than normal, participants asserted that they were able to continue to perform at a high level during training. Paoli et al. (2012) and Klement et al. (2013) reported initial fatigue during the first 1-2 weeks of LCHF dieting in their studies; however, this study was able to provide a more thorough qualitative analysis of this dietary intervention.

In addition, the case study design of this study was particularly beneficial as individual responses tended to be masked by group trends in other study designs. Some different individual responses were expressed. Individual perspectives added value to how mental and physical responses differ between each individual. For example, Participant 4 spoke of symptoms such as mental clarity and sustained energy during the morning which was a primary difference from other participants' responses. Furthermore, this investigation was able to gather additional qualitative data to give a more complete picture of the social and psychological stresses and experiences related to an LCHF diet. The evidence provided from this group of athletes showed that the LCHF diet prescribed could be acceptable as it can be both mentally and physiologically compatible with their training and lifestyle goals.

Conclusion and Future Research

This study provides direction for a variety of future research pathways. The findings of this investigation provide valuable data and insight into how this cohort of strength and power athletes physiologically and mentally responded to an LCHF diet. However, this study only used a small group of weightlifters and powerlifters. A larger study group would enable a cross-over design comparing a 'best practice' method against a non-calorie controlled LCHF diet (with standardised training programmes), which would be valuable as it would enable us to examine both quantitative and qualitative differences between the two. This research is useful as it adds to the limited body of knowledge of LCHF dieting for athletes and further validates that this is a dietary method that athletes could use to achieve their weight loss goals. A strength and power athlete may add the LCHF diet as another tool in their tool box of competition preparation techniques. An LCHF way of eating provides the opportunity for better health outcomes alongside a potential benefit to body composition, which rapid weight loss practices and more traditional 'best practice' methods do not provide (Brownell, et al., 1987; J. S. Volek, et al., 2009). This type of athlete could use an LCHF diet intermittently during different training phases whereby carbohydrate is reduced for competition preparation or increased for high volume (accumulation) phases. However, it is still unknown what the effect of carbohydrate cycling on performance is, and whether there is merit in this type of diet manipulation. In addition, whether a strength and power athlete is able to gain muscle mass on an LCHF diet is still a question that remains unanswered. If so, this would inevitably increase relative strength and power performance, which is a desired training outcome for all athletes (Volek & Phinney, 2012). Lastly, there is no current study investigating fuel utilisation during bouts of resistance training in strength and power athletes during an LCHF diet; this could be a valuable addition to the limited body of knowledge in this targeted area.

REFERENCES

Ahima, R. S. (2008). Revisiting leptin's role in obesity and weight loss. [Comment Research Support, Non-U.S. Gov't]. *The Journal Of Clinical Investigation, 118*(7), 2380-2383. doi: 10.1172/JCI36284

Ahima, R. S., Kelly, J., Elmquist, J. K., & Flier, J. S. (1999). Distinct physiologic and neuronal responses to decreased leptin and mild hyperleptinemia. *Endocrinology, 140*(11), 4923-4931.

Anderson, R., Barlett, S., Morgan, G., & Brownell, K. (1995). Weight loss, psychological, and nutritional patterns in competitive male body builders *International Journal of Eating Disorders, 18*(1), 49-57.

Anson, R. M., Guo, Z., de Cabo, R., Iyun, T., Rios, M., Hagepanos, A., . . . Mattson, M. P. (2003). Intermittent fasting dissociates beneficial effects of dietary restriction on glucose metabolism and neuronal resistance to injury from calorie intake. *Proceedings of the National Academy of Sciences of the United States of America, 100*(10), 6216-6220. doi: 10.1073/pnas.1035720100

Artioli, G., Gualano, B., Franchini, E., Scagliusi, F., Takesian, M., Fuchs, M., & Lancha, A. (2010). Prevalence, magnitude, and methods of rapid weight loss among judo competitors. *Medicine and Science in Sport and Exercise, 42*(3), 436-442.

Astrup, A., Larsen, T. M., & Harper, A. (2004). Atkins and other low-carbohydrate diets: hoax or an effective tool for weight loss? *The Lancet, 364*(9437), 897-899. doi: 10.1016/s0140-6736(04)16986-9

Austin, M. A., Breslow, J. L., Hennekens, C. H., Buring, J. E., Willett, W. C., & Krauss, R. M. (1988). Low-density lipoprotein subclass patterns and risk of myocardial infarction. *The Journal of American Medical Association 260*(13), 1917-1921.

Bergström, J., Hermansen, L., Hultman, E., & Saltin, B. (1967). Diet, Muscle Glycogen and Physical Performance. *Acta Physiologica Scandinavica, 71*(2-3), 140-150. doi: 10.1111/j.1748-1716.1967.tb03720.x

Bingham, S., A., Gill, C., Welch, A., Day, K., Cassidy, A., Khaw, K., . . . Day, N. (1994). Comparison of dietary assessment methods in nutritional epidemiology : weighed records v. 24 h recalls, food-frequency questionnaires and estimated-diet records. *British Journal of Nutrition, 1994*(72), 619-643.

Blake, H. (2008). Innovation in practice: mobile phone technology in patient care. *British Journal of Community Nursing, 13*(4), 160-165.

Blazevich, A. J., Gill, N. D., & Zhou, S. (2006). Intra- and intermuscular variation in human quadriceps femoris architecture assessed in vivo. [Comparative Study]. *Journal of anatomy, 209*(3), 289-310. doi: 10.1111/j.1469-7580.2006.00619.x

Brown, R. C., & Cox, C. M. (1998). Effects of high fat versus high carbohydrate diets on plasma lipids and lipoproteins in endurance athletes. *Medicine and Science in Sports and Exercise, 30*(12), 1677-1683.

Brownell, K., Steen, S., & Wilmore, J. (1987). Weight regulation practices in athletes: analysis of metabolic and health effects. *Medicine and Science in Sport and Exercise, 19*(6), 546-556.

Burke, L., & Kiens, B. (2006). "Fat adaptations" for athletic performance: the nail in the coffin? *Journal of Applied Physiology, 100*, 7-8.

Burke, L. M., Hawley, J. A., Wong, S. H. S., & Jeukendrup, A. E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences, 29*(SUPPL. 1), S17-S27.

Burke, L. M., Kiens, B., & Ivy, J. L. (2004). Carbohydrates and fat for training and recovery. [Review]. *Journal of Sports Sciences, 22*(1), 15-30. doi: 10.1080/0264041031000140527

Castelli, W. (1996). Lipids, risk factors and ischaemic heart disease. *Atherosclerosis*, S1-S9.

Cheng, B., Karamizerak, O., Noakes, T., Dennis, S., C., & Lambert, E. V. (1994). Time course of changes in rat muscle enzymes involved in fat oxidation following exercise training and a high fat diet. *Clinical Science, 87 (suppl.)*(17).

Churchley, E., Coffey, V., Pedersen, D., Shield, A., Carey, K., Cameron-Smith, D., & Hawley, J., A. (2007). Influence of preexercise muscle glycogen content on transcriptional activity of metabolic and myogenic genes in well-trained humans. *Journal of Applied Physiology, 102*, 1604-1611. doi: 10.1152/japplphysiol.01260.2006.-To

Civitarese, A., E., Carling, S., Heilbronn, L., K., Hulver, M., H., Ukropcova, B., Deutsch, W., A., . . . Ravussin, E. (2007). Calorie restriction increases muscle mitochondrial biogenesis in healthy humans. *PloS Medicine 4*(3), 485-494. doi: 10.1371/journal

Creer, A., Gallagher, P., Slivka, D., Jemiolo, B., Fink, W., & Trappe, S. (2005). Influence of muscle glycogen availability on erk1/2 and akt signaling after resistance exercise in human skeletal muscle. *Journal of Applied Physiology, 99*, 950-956. doi: 10.1152/japplphysiol.00110.2005.-Two

Dallmeier, D., & Koenig, W. (2014). Strategies for vascular disease prevention: the role of lipids and related markers including apolipoproteins, low-density lipoproteins (LDL)-particle size, high sensitivity C-reactive protein (hs-CRP), lipoprotein-associated phospholipase A2 (Lp-PLA(2)) and lipoprotein(a) (Lp(a)). [Review]. *Best practice & research. Clinical endocrinology & metabolism, 28*(3), 281-294. doi: 10.1016/j.beem.2014.01.003

Dansinger, M., Gleason, J., Griffith, J., Selker, H., & Schaefer, E. (2005). Comparison of the atkins, ornish, weight watchers, and zone diets for weight lossand heart disease risk reduction. *Journal of American Medical Association, 293*(1), 43-53.

De Graaf, C., Blom, W., Smeets, P., Stafleu, A., & Hendricks, H. (2004). Biomarkers of satiation and satiety. *American Journal of Clinical Nutrition, 79*, 946-961.

Dias, C., Garg, R., Wood, L., & Garg, M. (2014). Saturated fat consumption may not be the main cause of increased blood lipid levels. *Medical Hypotheses, 82*(2), 187-195.

Dipla, K., Makri, M., Zafeiridis, A., Soulas, D., Tsalouhidou, S., Mougios, V., & Kellis, S. (2008). An isoenergetic high-protein, moderate-fat diet does not compromise strength and fatigue during resistance exercise in women. *The British Journal Of Nutrition, 100*(2), 283-286. doi: http://dx.doi.org/10.1017/S0007114507898679

Doucet, E., Imbeault, P., St-Pierre, S., Almeras, N., Mauriege, P., Richard, D., & Tremblay, A. (2000). Appetite after weight loss by energy restriction and a low-fat diet-exercise follow-up. *International Journal of Obesity, 24*, 906-914.

Ebbeling, C. B., Swain, J. F., Feldman, H. A., Wong, W. W., Hachey, D. L., Garcia-Lago, E., & Ludwig, D. S. (2012). Effects of dietary composition on energy expenditure during weight-loss maintenance. *The Journal of American Medical Association, 307*(24), 2627-2634.

Feinman, R. D., Pogozelski, W. K., Astrup, A., Bernstein, R. K., Fine, E. J., Westman, E. C., . . . Worm, N. (2015). Dietary carbohydrate restriction as the first approach in diabetes management: critical review and evidence base. [Research Support, Non-U.S. Gov't]. *Nutrition, 31*(1), 1-13. doi: 10.1016/j.nut.2014.06.011

Fernstrom, J. D., & Wurtman, R. J. (1971). Brain serotonin content: increase following ingestion of carbohydrate diet. *Science*, *174*(4013), 1023-1025.

Forsythe, C., E., Phinney, S., D., Feinman, R., D., Volk, B., M., Fredenreich, D., Quann, E., E. , . . . Volek, J., S. . (2010). Limited effect of dietary saturated fat on plasma saturated fat in the context of a low carbohydrate diet. *Lipids, 45*(10), 947-962.

Forsythe, C., E., Phinney, S., D., Fredenreich, D., Quann, E., E., Wood, R., J., Bibus, D., M., . . . Volek, J., S. . (2008). Comparison of low fat and low carbohydrate diets on circulating fatty acids composition and markers of inflammation. *Lipids, 43*(1), 65-77.

Freedman, L. S., Schatzkin, A., Midthune, D., & Kipnis, V. (2011). Dealing with dietary measurement error in nutritional cohort studies. *Journal of the National Cancer Institute, 103*(14), 1086-1092. doi: 10.1093/jnci/djr189

Friday, K., Failor, R., Childs, M., & Bierman, E. (1991). Effects of n-3 and n-6 fatty acid-enriched diets on plasma lipoproteins and apolipoproteins in heterozygous familial hypercholesterolemia. *Atherosclerosis and Thrombosis, 11*, 47-54.

Garthe, I., Raastad, T., Refsnes, P. E., Koivisto, A., & Sundgot-Borgen, J. (2011). Effect of two different weight-loss rates on body composition and strength and power-related performance in elite athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 21*, 97-104.

Gavin, H. (Ed.). (2008). *Understanding Research Methods and Statistics in Psychology*. London: Sage.

Gibson, A. A., Seimon, R. V., Lee, C. M., Ayre, J., Franklin, J., Markovic, T. P., . . . Sainsbury, A. (2015). Do ketogenic diets really suppress appetite? A systematic review and meta-analysis. *Obesity reviews : an official journal of the International Association for the Study of Obesity, 16*(1), 64-76. doi: 10.1111/obr.12230

Goedecke, J., Christie, C., Wilson, G. D., Dennis, S. C., Noakes, T., Hopkins, W. G., & Lambert, E. V. (1999). Metabolic Adaptations to a High-Fat Diet in Endurance Cyclists. *Metabolism, 48*(12), 1509-1517.

Greenhaff, P. L., Gleeson, M., & Maughan, R. (1987). The effects of dietary manipulation on blood acid-base status and the performance of high intensity exercise. *European Journal of Applied Physiology, 56*, 331-337.

Greenhaff, P. L., Gleeson, M., & Maughan, R. J. (1988). Diet-induced metabolic acidosis and the performance of high intensity exercise in man. *European journal of applied physiology and occupational physiology, 57*(5), 583-590.

Grotto, D., & Zied, E. (2010). The standard american diet and Its relationship to the health status of americans. *Nutrition in Clinical Practice, 25*(6), 603-611.

Haff, G. G. (2001). Roundtable Discussion: Low Carbohydrate Diets and Anaerobic Athletes. *Strength and Conditioning Journal, 23*(3), 42-61.

Haff, G. G., & Whitley, A. (2002). Low-carbohydrate diets and high-intensity anaerobic exercise. *Strength and Conditioning Journal, 24*(4), 42-53.

Halson, S. L., Bridge, M. W., Meeusen, R., Busschaert, B., Gleeson, M., Jones, D. A., & Jeukendrup, A. E. (2002). Time course of performance changes and fatigue markers during intensified training in trained cyclists. *Journal of Applied Physiology, 93*(3), 947-956. doi: 10.1152/japplphysiol.01164.2001

Halton, T., L., & Hu, F., B. (2004). The effects of high protein diets on thermogenesis, satiety and weight loss: a critical review. *Journal of American College of Nutrition 23*(5), 373-385.

Harcombe, Z., Baker, J., Cooper, S., Davies, B., Sculthorpe, N., DiNicolantonio, J., & Grace, F. (2015). Evidence from randomised controlled trials did not support the introduction of dietary fat guidelines in 1977 and 1983: a systematic review and meta-analysis. *Open Heart, 2*, 1-7. doi: 10.1136/openhrt-201400019610.1136/openhrt-2014-000196

Havemann, L., West, S., Goedecke, J., Macdonald, I., Gibson, A., Noakes, T., & Lambert, E., V. (2006). Fat adaptation followed by carbohydrate loading compromised high-intensity sprint performance. *Journal of Applied Physiology, 100*, 194-202.

Helms, E. R., Aragon, A. A., & Fitschen, P. J. (2014). Evidence-based recommendations for natural bodybuilding contest preparation: Nutrition and supplementation. *Journal of the International Society of Sports Nutrition, 11*(1). doi: 10.1186/1550-2783-11-20

Helms, E. R., Zinn, C., Rowlands, D. S., & Brown, S. R. (2014). A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: a case for higher intakes. *International Journal of Sport Nutrition and Exercise Metabolism, 24*(2), 127-138. doi: 10.1123/ijsnem.2013-0054

Helms, E. R., Zinn, C., Rowlands, D. S., Naidoo, R., & Cronin, J. (2014). High-Protein Low-Fat Short-Term Diet Results in Less Stress and Fatigue Than Moderate-Protein Moderate-Fat Diet During Weight Loss in Male Weightlifters, A Pilot Study. *International Journal of Sport Nutrition and Exercise Metabolism*. doi: 10.1123/ijsnem.2014-0056

Hester, D., Hunter, G., Shuleva, K., & Kekes-Sabo, T. (1990). Bridging the gap-practical application: review and evaluation of relative strength handicapping models. *National Strength and Conditioning Association Journal, 12*(1), 54-57.

Hetherington, M., Pirie, L., & Nabb, S. (2002). Stimulus satiation: effects of repeated exposure to foods on pleasantness and intake. *Appetite, 38*, 19-28.

Hopkins, P. N. (2003). Familial hypercholesterolemia—Improving treatment and meeting guidelines. *International Journal of Cardiology, 89*(1), 13-23. doi: 10.1016/s0167-5273(02)00420-5

Horswill, C. A., Hickner, R. C., Scott, J. R., Costill, D. L., & Gould, D. (1990). Weight loss, dietary carbohydrate modifications, and high intensity physical performance. *Medicine and Science in Sports and Exercise, 22*(4), 470-476.

Hu, T., Mills, K. T., Yao, L., Demanelis, K., Eloustaz, M., Yancy, W. S., Jr., . . . Bazzano, L. A. (2012). Effects of low-carbohydrate diets versus low-fat diets on metabolic risk factors: a meta-analysis of randomized controlled clinical trials. *American journal of epidemiology, 176 Suppl 7*, S44-54. doi: 10.1093/aje/kws264

Illner, A. K., Freisling, H., Boeing, H., Huybrechts, I., Crispim, S. P., & Slimani, N. (2012). Review and evaluation of innovative technologies for measuring diet in nutritional epidemiology. *International journal of epidemiology, 41*(4), 1187-1203. doi: 10.1093/ije/dys105

Jeukendrup, A. E. (2011). Nutrition for endurance sports: marathon, triathlon, and road cycling. [Review]. *Journal of Sports Sciences, 29 Suppl 1*, S91-99. doi: 10.1080/02640414.2011.610348

Johnstone, A., Horgan, G., Murison, S., Bremner, D., & Lobley, G. (2008). Effects of a high-protein ketogenic diet on hunger, appetite, and weight loss in obese men feeding ad libitum. *American Journal of Clinical Nutrition, 87*, 44-55.

Kelley, D., E., He, J., Menshikova, E., V., & Ritov, V., B. (2002). Dysfunction of mitochondria in human skeletal muscle in type 2 diabete. *Diabetes, 51*, 2944–2950.

Klement, R. J., Frobel, T., Albers, T., Fikenzer, S., Prinzhausen, J., & U., K. (2013). A pilot case study on the impact of a self-prescribed ketogenic diet on biochemical parameters and running performance in healthy and physically active individuals. *Nutrition and Metabolism, 1*(1), 1-27.

Krauss, R., Blanche, P., Rawlings, R., Fernstrom, H., & Williams, P. (2006). Separate effects of reduced carbohydrate intake and weight loss on atherogenic dyslipidemia. *The American Journal of Clinical Nutrition, 83*, 1025-1031.

Krauss, R. M. (2014). All low-density lipoprotein particles are not created equal. [Comment Editorial Research Support, Non-U.S. Gov't]. *Arteriosclerosis, thrombosis, and vascular biology, 34*(5), 959-961. doi: 10.1161/ATVBAHA.114.303458

Kwah, L., Pinto, R., J, D., & Herbert, R. (2013). Reliability and validity of ultrasound measurements of muscle fascicle length and pennation in humans: a systematic review. *Journal of Applied Physiology, 114*, 761-769. doi: 10.1152/japplphysiol.01430.2011.-Ultrasound

Lambert, Hawley, Goedecke, Noakes, & Dennis. (1997). Nutritional strategies for promoting fat utilization and delaying the onset of fatigue during prolonged exercise. *Journal of Sports Sciences, 15*(3), 315-324.

Lambert, E., Speechly, D., P., Dennis, S., C., & Noakes, T. (1994). Enhanced endurance in trained cyclists during moderate intensity exercise following 2 weeks adaptation to a high fat diet. *European Journal of Applied Physiology, 69*, 287-293.

Lambert, E., V., Hawley, J., A., Goedecke, J., Noakes, T., & Dennis, S., C. (1997). Nutritional strategies for promoting fat utilization and delaying the onset of fatigue during prolonged exercise. *Journal of Sports Sciences, 15*(3), 315-324.

Langhans, W. (2008). Fatty acid oxidation in the energostatic control of eating--a new idea. *Appetite, 51*(3), 446-451. doi: 10.1016/j.appet.2008.06.014

Layman, D., K., Boileau, R., A., Erikson, D., J., Painter, J., E., Shiue, H., Sather, C., & Christou, D., D. (2003). A reduced ratio of dietary carbohydrate to protein improves body composition and blood lipid profiles during weight loss in adult women. *The Journal of Nutrition, 133*, 411-417.

Leibel, R., L., Rosenbaum, M., & Hirsch, J. (1995). Changes in energy expenditure resulting from altered body weight. *New England Journal of Medicine, 332*, 621-628.

Leidy, H. J., Armstrong, C. L., Tang, M., Mattes, R. D., & Campbell, W. W. (2010). The influence of higher protein intake and greater eating frequency on appetite control in overweight and obese men. *Obesity, 18*(9), 1725-1732. doi: 10.1038/oby.2010.45

Levine, J., A. , Eberhardt, N., L., & Jensen, M., D. (1999). Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science 283*, 212-214.

Manninen, A. H. (2006). Very-low-carbohydrate diets and preservation of muscle mass. *Nutrition & Metabolism, 3*, 9. doi: 10.1186/1743-7075-3-9

Mattson, M. P., Allison, D. B., Fontana, L., Harvie, M., Longo, V. D., Malaisse, W. J., . . . Panda, S. (2014). Meal frequency and timing in health and disease. [Research Support, N.I.H., Extramural Research Support, N.I.H., Intramural Research Support, Non-U.S. Gov't]. *Proceedings of the National Academy of Sciences of the United States of America, 111*(47), 16647-16653. doi: 10.1073/pnas.1413965111

Matuszak, M., E., Fry, A., C., Weiss, L., W., Ireland, T., R., & McKnight, M., M. (2003). Effect of rest interval length on repeated 1 reptition maximum back squat. *Journal of Strength and Conditioning Research, 17*(4), 634-637.

McGuigan, M., R., & Kane, M., K. (2004). Reliability of performance of elite olympic weightlifters. *Journal of Strength and Conditioning Research, 18*(3), 650-653.

Melton, P., Kissileff, H., & Pi-Sunyer, F. (1992). The effect of chlecystokinin (cck-8) affects gastric pressure and ratings of hunger and fullness. *American Journal of Physiology, 263*, 452-256.

Mendes, S., Tritto, A., Guilherme, J., P., Solis, M., Y., Vieira, D., E., Franchini, E., . . . Artioli, G. (2013). Effect of rapid weight loss in performance in combat sport male athletes: does adaptation to chronic weight cycling play a role? . *British Journal of Sports Nutrition, 47*(18), 1155-1160.

Mensink, R., & Katan, M. (1992). Effect of dietary fatty acids on serum lipids and lipoproteins: a ,eta-analysis of 27 trials. *Arteriosclerosis and Thrombosis, 12*, 911-919.

Milder, J., & Patel, M. (2012). Modulation of oxidative stress and mitochondrial function by the ketogenic diet. [Review]. *Epilepsy research, 100*(3), 295-303. doi: 10.1016/j.eplepsyres.2011.09.021

Mitch, W. E., & Goldberg, A. L. (1996). Mechanisms of muscle wasting: the role of the ubiquitin proteasome pathway. *New England Journal of Medicine, 335*(25), 1897-1905.

Mitchell, J. B., & DiLauro, P. C. (1997). The effect of preexercise carbohydrate status on resistance exercise performance. *International Journal of Sport Nutrition, 7*(3), 185.

Miyatani, M., Kanehisa, H., & Fukunaga, T. (2000). Validity of bioelectrical impedance and ultrasonographic method for estimating the muscle volume of the upper arm. *European Journal of Applied Physiology, 82*, 391-396.

Miyatani, M., Kanehisa, H., Ito, M., Kawakami, Y., & Fukunaga, T. (2004). The accuracy of volume estimates using ultrasound muscle thickness measurements in different muscle groups. [Clinical TrialComparative Study Controlled Clinical Trial Research Support, Non-U.S. Gov't Validation Studies]. *European Journal of Applied Physiology, 91*(2-3), 264-272. doi: 10.1007/s00421-003-0974-4

Mora, S. (2009). Advanced lipoprotein testing and subfractionation are not (yet) ready for routine clinical use. *Circulation, 119*(17), 2396-2404. doi: 10.1161/CIRCULATIONAHA.108.819359

Morton, G. J., Cummings, D. E., Baskin, D. G., Barsh, G. S., & Schwartz, M. W. (2006). Central nervous system control of food intake and body weight. *Nature, 443*(7109), 289-295. doi: 10.1038/nature05026

Naude, C. E., Schoonees, A., M., S., Young, T., Garner, P., & Volmibk, J. (2014). Low Carbohydrate versus Isoenergetic Balanced Diets for Reducing Weight and Cardiovascular Risk: A Systematic Review and Meta-Analysis. *PLoS One, 9*(7), 1-30. doi: 10.1371/journal.pone.0100652.t001

Noakes, T., Volek, J. S., & Phinney, S. D. (2014). Low-carbohydrate diets for athletes: what evidence? [Editorial]. *British Journal of Sports Medicine, 48*(14), 1077-1078. doi: 10.1136/bjsports-2014-093824

NZDA. (2008). Position of the New Zealand Dietetic Association (Inc): Nutrition for exercise and sport in New Zealand. *Nutrition & Dietetics, 65*, 70-80. doi: 10.1111/j.1747-0080.2008.00305.x

NZPL. (2015). Rules/qualifying/representing nz. http://www.nzpowerlifting.co.nz/

Oppliger, R., Steen, S., & Scott, J. (2003). Weight loss practices of college wrestlers *International Journal of Sports Nutrition and Exercise Metabolism, 13*(1), 29-46.

OWNZ. (2015). 2015 Open Grading Standards. http://olympicweightlifting.nz/national-championship-qualifying-standards/

Paoli, A., Grimaldi, K., D'Agostino, D., Cenci, L., Moro, T., Bianco, A., & Palma, A. (2012). Ketogenic diet does not affect strength performance in elite artistic gymnasts. *Journal of the International Society of Sports Nutrition, 9*, 1-9.

Paul, D., R., Novotny, J., A., & Rumpler, W., V. (2004). Effects of the interaction of sex and food intake on the relation between energy expenditure and body composition. *The American Journal of Clinical Nutrition, 79*(385-389).

Phillips, S. M., & Van Loon, L. J. (2011). Dietary protein for athletes: from requirements to optimum adaptation. [Review]. *Journal of Sports Sciences, 29 Suppl 1*, S29-38. doi: 10.1080/02640414.2011.619204

Phinney, S., Birstrian, B., Evans, W., Gervino, E., & Blackburn, G. (1983). The human metabolic response to chronic ketosis without caloirc restriction: preservation of submaximal exercise capability with reduced carbohydrate oxidation. *Metabolism, 32*(8), 769-776.

Phinney, S. D. (2004). Ketogenic diets and physical performance. *Nutrition & Metabolism, 1*(1), 2. doi: 10.1186/1743-7075-1-2

Riley, R. E. (1999). Popular weight loss diets: health and exercise implications. *Sports Medicine, 18*, 691–701.

Rodriguez, N. R., DiMarco, N. M., & Langley, S. (2009). Nutrition and athletic performance. *Medicine and Science in Sports and Exercise, 41*(3), 709-731. doi: 10.1249/MSS.0b013e31890eb86

Rodriguez, N. R., DiMarco, N. M., Langley, S., Denny, S., Hager, M. H., Manore, M. M., . . . Dietitians, C. (2009). Nutrition and Athletic Performance. *Medicine and Science in Sports and Exercise, 41*(3), 709-731. doi: 10.1249/MSS.0b013e31890eb86

Sawyer, J. C., Wood, R. J., Davidson, P. W., Collins, S. M., Matthews, T. D., Gregory, S. M., & Paolone, V. J. (2013a). Effects of a Short-Term Carbohydrate-Restricted Diet on Strength and Power Performance. *Journal of Strength and Conditioning Research, 27*(8), 2255-2262. doi: 10.1519/JSC.0b013e31827da314

Sawyer, J. C., Wood, R. J., Davidson, P. W., Collins, S. M., Matthews, T. D., Gregory, S. M., & Paolone, V. J. (2013b). Effects of a short-term carbohydrate restricted diet on strength and power performance. *Journal of Strength and Conditioning Research, 27*(8), 2255-2262. doi: 10.1519/JSC.0b013e31827da314

Scharrer, E. (1999). Control of food intake by fatty acid oxidation and ketogenesis. *Nutrition, 15*(9), 704-714.

Shai, I., Schwarzfuchs, D., Henkin, Y., Shahar, D. R., Witkow, S., Greenberg, I., . . . Stampfer, M. (2008). Weight loss with a low-carbohydrate, mediterranean or low-fat diet. *The New England Journal of Medicine, 359*(3), 229-241.

Shimazu, T., Hirschey, M. D., Newman, J., He, W., Shirakawa, K., Le Moan, N., . . . Verdin, E. (2013). Suppression of oxidative stress by beta-hydroxybutyrate, an endogenous histone deacetylase inhibitor. *Science 339*(6116), 211-214.

Siri-Tarino, P. W., Sun, Q., Hu, F. B., & Krauss, R. M. (2010). Meta-analysis of prospective cohort studies evaluating the association of saturated fat with cardiovascular disease. [Meta-Analysis Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't]. *The American Journal of Clinical Nutrition, 91*(3), 535-546. doi: 10.3945/ajcn.2009.27725

Slater, G., & Phillips, S. (2011). Nutrition guidelines for strength sports: sprinting, weightlifting, throwing events, and bodybuilding. *Journal of Sports Sciences, 29 Suppl 1*, S67-77.

Slater, G., & Phillips, S. M. (2011). Nutrition guidelines for strength sports: Sprinting, weightlifting, throwing events, and bodybuilding. *Journal of Sports Sciences, 29*(SUPPL. 1), S67-S77. doi: 10.1080/02640414.2011.574722

Stern, L., Iqbal, N., Seshadri, P., Chicano, K., L., Dally, D., A., McGrory, J., . . . Samaha, F., F. (2004). The effects of low carbohydrate versus conventional weight loss diets in severely obese adults: one-year follow-up of a randomized trial. *Annals of Internal Medicine, 140*(10), 778-796.

Stewart, A., Marfell-Jones, M., Olds, T., & de Ridder, H. (Eds.). (2011). *International standards for anthropometric assessment*. Lower Hutt: New Zealand: The Internastional Society for the Advancement of Kinathropometry.

Storey, A. G., Birch, N. P., Fan, V., & Smith, H. K. (2015). Stress responses to short-term intensified and reduced training in competitive weightlifters. *Scandinavian Journal of Medicine & Science in Sports*. doi: 10.1111/sms.12400

Sundgot-Borgen, J., & Garthe, I. (2011). Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. [Review]. *Journal of Sports Sciences, 29 Suppl 1*, S101-114. doi: 10.1080/02640414.2011.565783

Symons, J. D., & Jacobs, I. (1989). High-intensity exercise performance is not impaired by low intramuscular glycogen. *Medicine and Science in Sports and Exercise, 21*(5), 550-557.

Tesch, P. A., Thorsson, A., & Fujitsuka, N. (1989). Creatine phosphate in fiber types of skeletal muscle before and after exhaustive exercise. *Journal of Applied Physiology, 66*(4), 1756-1759.

Van Zant, R. S., Conway, J. M., & Seale, J. L. (2002). A moderate carbohydrate and fat diet does not impair strength performance in moderately trained males. *Journal of Sports Medicine and Physical Fitness, 42*(1), 31-37.

Vanderburgh, P., & Batterham, A. (1999). Validation of the wilks powerlfiting formula. *Medicine and Science in Sport and Exercise, 31*(12), 1869-1875.

Veldhorst, M. A., Westerterp, K. R., van Vught, A. J., & Westerterp-Plantenga, M. S. (2010). Presence or absence of carbohydrates and the proportion of fat in a high-protein diet affect appetite suppression but not energy expenditure in normal-weight human subjects fed in energy balance. [Randomized Controlled Trial]. *The British Journal Of Nutrition, 104*(9), 1395-1405. doi: 10.1017/S0007114510002060

Volek, J., Gomes, A. I. D., & Kraemer, W., J. (2000). Fasting Lipoprotein and Postprandial Triacylglycerol Responses to a Low-Carbohydrate Diet Supplemented with n-3 Fatty Acids. *Journal of the American College of Nutrition, 19*(3), 383-391. doi: 10.1080/07315724.2000.10718935

Volek, J., & Phinney, S. (Eds.). (2012). *The art and science of low carbohydrate performance.* : San Bernardino, CA: Beyond Obesity LLC.

Volek, J., Sharman, M., Gomez, A., Judelson, D., Rubin, M., Watson, G., . . . Kraemer, W. (2004). Comparison of energy-restricted very low-carbohydrate and low-fat diets on weight loss and body composition in overweight men and women. *Nutrition & Metabolism, 1*(1), 13. doi: 10.1186/1743-7075-1-13

Volek, J. S., Forsythe, C. E., & Kraemer, W. J. (2006). Nutritional aspects of women strength athletes. *British Journal of Sports Medicine, 40*(9), 742-748.

Volek, J. S., Noakes, T., & Phinney, S. D. (2015). Rethinking fat as a fuel for endurance exercise. *European Journal of Sport Science, 15*(1), 13-20. doi: 10.1080/17461391.2014.959564

Volek, J. S., Phinney, S. D., Forsythe, C. E., Quann, E. E., Wood, R. J., Puglisi, M. J., . . . Feinman, R. D. (2009). Carbohydrate restriction has a more favorable impact on the metabolic syndrome than a low fat diet. [Randomized Controlled Trial Research Support, Non-U.S. Gov't Research Support, U.S. Gov't, Non-P.H.S.]. *Lipids, 44*(4), 297-309. doi: 10.1007/s11745-008-3274-2

WADA. (2015). The world anti-doping coade: the 2015 prohibited list: international standard

Walberg, J. L., Leidy, M. K., Sturgill, D. J., Hinkle, D. E., Ritchey, S. J., & Sebolt, D. R. (1988). Macronutrient content of a hypoenergy diet affects nitrogen retention and muscle function in weight lifters. *International Journal of Sports Medicine, 9*(4), 261-266.

Weimann, E., Blum, W. F., Witzel, C., Schwidergall, S., & Böhles, H. J. (1999). Hypoleptinemia in female and male elite gymnasts. [Article]. *European Journal of Clinical Investigation, 29*(10), 853-860. doi: 10.1046/j.1365-2362.1999.00542.x

Westman, E., C., Feinman, R. D., Mavropoulos, J., C., Vernon, M., C., Volek, J., Wortman, J., A., . . . Phinney, S. (2007). Low-carbohydrate nutrition and metabolism. *American Journal of Clinical Nutrition, 86*, 276-284.

Westman, E., C., Yancy, W., S., Edman, J., S., Tomlin, K., F., & Perkins, C., E. (2002). Effect of 6-Month adherence to a very low carbohydrate diet program. *The American Journal of Medicine, 113*, 30-36.

Yeo, W. K., Carey, A. L., Burke, L., Spriet, L. L., & Hawley, J. A. (2011). Fat adaptation in well-trained athletes: effects on cell metabolism. [Review]. *Applied physiology, nutrition, and metabolism = Physiologie* *appliquee, nutrition et metabolisme, 36*(1), 12-22. doi: 10.1139/H10-089

APPENDICES

Appendix 1: Ethics approval, Auckland University of Technology Ethics Committee

AUT UNIVERSITY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

AUTEC SECRETARIAT

26 May 2014

Caryn Zinn
Faculty of Health and Environmental Sciences

Dear Caryn

Re Ethics Application: **14/112 Effect of an 8-week low carbohydrate high faat (LCHF) diet on maximal strength performance, body composition and diet acceptability in competitive Olympic weightlifters and power lifters.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 26 May 2017.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 26 May 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 26 May 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Simon Chatterton simon_chatt@hotmail.com

Auckland University of Technology Ethics Committee
WA505F Level 5 WA Building City Campus

Appendix 2: Participant information sheet

Participant Information Sheet

Date Information Sheet Produced:

17/03/2014

Project Title

Does an 8-week low carbohydrate high fat diet affect maximal strength performance, body composition and diet acceptability in competitive Olympic weightlifters and powerlifters?

An Invitation

Hi, my name is Simon Chatterton and I am a Masters student at AUT University. On behalf of my supervisors Dr Caryn Zinn and Dr Adam Storey, I would like to personally invite you to assist us in our project that aims to determine the effect of a low carbohydrate high fat diet on strength performance, anthropometrics and diet acceptability in competitive Olympic weightlifters and power lifters.

It is entirely your choice as to whether you participate in the project or not. If you decide you no longer want to participate you are free to withdraw yourself or any information that you have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way. Your consent to participate in this research will be indicated by you signing and dating the consent form. Signing the consent form indicates the you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers at AUT.

What is the purpose of this research?

This research aims to investigate the effect of a low carbohydrate high fat diet on strength performance, anthropometric measures and diet acceptability in competitive Olympic weightlifters and powerlifters. The results of this study could help to inform coaches and athletes as to whether the implementation of such a diet could be a feasible option for reducing weight prior to competition. The results will also produce a Master's thesis with the view of the results being published in a scientific journal article.

How was I identified and why am I being invited to participate in this research?

Your coach and I have been working together with this project, where he has told me that you may possibly be interested, as an elite Olympic weightlifter or powerlifter, in being involved in this study. If you were to volunteer, you will be verbally presented with further background information about the low carbohydrate high fat diet, the time commitment during the study, the activities involved and the potential benefits. This will be finished with a contact email if you are interested in being involved in this study. You have been asked to participate in this research as you fit our research criteria, being an Olympic weightlifter or a powerlifter between ages 21-35, and qualify as a c class (or over) Olympic lifter or a bronze class (or over) powerlifter with no current injuries.

What will happen in this research?

The structure of the study will run as follows:

The study will run for 16 weeks and will be split into three components. Firstly, an initial 4-week baseline with regular collection of your recorded habitual diet, skinfolds, and stress questionnaires will be taken. A baseline period for data collection is used to give us a snapshot of your current lifestyle before the dietary intervention. You will then begin your 8-week low carbohydrate high fat diet, which will involve two one-on-one interviews, one focus group, recording your diet weekly, skinfold measurements, two blood tests and strength measures pre and post the 8-week dietary intervention. Lastly, you will return back to your normal diet for four weeks, during which time you will record your diet weekly and you will be required to attend one final focus group.

On the days that you have your interviews and focus groups, skinfolds will be measured beforehand. This is also the same with the days you will perform strength assessments; an ultrasound scan will be taken of your quadriceps prior to these measures.

Food Diaries

Once you have decided to participate in the study you will be asked to meet with me to discuss the details. In addition, you will be asked about certain aspects of your current diet and I will answer any concerns or question that you may have. After this meeting, your skinfolds will be taken from eight sites around your body. These sites include; triceps, biceps, subscapularis thigh iliac crest, supraspinale, abdominal and calf. After this initial meeting, your 4-week baseline measure collection will begin.

For the first four weeks, you will continue with your normal diet. One of your first requirements is to complete weekly food diaries which you will send to me via email with the use of Easy Diet Diary®. This is an iDevice application that is free to download, and can be emailed straight from your device to my email address. This will be collected and analysed to identify your daily intake of protein, fat and carbohydrate.

After the 4-week baseline period we will negotiate a start date for you to begin the second stage of an 8-week low carbohydrate high fat diet. We will allow you a couple days before the intervention for shopping and for us to perform a second skinfolds test before starting in to the low carbohydrate high fat diet. You will be asked to continue with weekly food diaries for us to see the shift in carbohydrate and fat intake.

Once you have completed the eight-week low carbohydrate high fat diet, you be asked to return back to your normal diet while still continuing your weekly food diaries.

Stress questionnaires, Interviews, Focus Groups

During the entire 16-week study period a stress questionnaire will be used to look at your training and lifestyle. Each question involves ticking a box that says: worse than normal, normal or better than normal. These forms will be handed to you each week, where you are required to fill them out each day in the morning. At the start of each week I will collect your completed stress questionnaires from the previous week.

During the 16-week study you will be required to have two interviews and two focus group sessions. The first interview will be performed the week leading into the8-week low carbohydrate high fat diet. This will involve a sit down interview with us (Project supervisor and Registered Dietitian, Caryn Zinn and I). In this interview, we will be enquiring about your current diet and its impact on your lifestyle. Also, we will be giving you the appropriate information for the low carbohydrate high fat diet. At the end of this interview you will also receive a low carbohydrate high fat food starter pack; this will include foods such as nuts and coconut oil. Prior to this interview, your skinfold measurements (as listed above) will be recorded.

The second interview will be during week four of the 8-week low carbohydrate high fat diet. This conversation will run in a similar fashion to the previous interview. Prior to this interview, your skinfolds will be measured again.

During the last week of your 8-week low carbohydrate high fat intervention you will join the rest of the participants for a focus group interview session. This will be directed by me, where I will open the meeting and ask questions to the group to produce a free flowing conversation about the experience of the low carbohydrate high fat diet. A third skinfold measure will be taken during the last week of the 8-week dietary intervention prior to this focus group.

Finally, in the last week of the 4-week ‘return to normal’ phase, a second focus group will be organised and will be run in a similar fashion to the previous focus group.

Ultrasound and Strength Measures

The first ultrasound and strength measures will be taken the week prior to you starting your 8-week low carbohydrate high fat diet. The ultrasound will be performed on your quadriceps to look at your muscle cross-sectional area and pennation angle. Pennation angle refers to the orientation/angle of your existing muscle fibres. This is a safe non-invasive tool, using a sensor that transmits an ultrasonic sound frequency (that is outside the ranges of the human ear) to produce a digital image. Next, if you are an Olympic weightlifter you will be required to perform a 1 repetition maximum of your snatch and clean and jerk as done in competition. If you are a powerlifter you will be performing a one repetition maximum of your back squat, bench press and deadlift as done in competition.

The last week of the 8-week low carbohydrate high fat dietary intervention period will involve a second ultrasound and strength assessment which will be conducted in the same fashion as previously mentioned.

Blood tests

A blood test appointment will be negotiated with you within the week prior to the 8-week low carbohydrate high fat diet. This will involve a skilled professional drawing a small sample of blood to measure your lipid profile and two hormones. A second appointment will be organised during the last week of the 8-week intervention, measuring the same markers.

If at any stage during this 8-week diet you have a question regarding the diet, feel free to contact me using the contact details provided at the end of this participant information sheet.

What are the discomforts and risks?

Strength tests, such as the one repetition maximum snatch and clean and jerk, carry the same inherent risk that weight training carries. There is the potential of injury, though the risk is minimal.

The analysis of body composition, through skin fold testing, may create embarrassment or discomfort. There may be some minor pain with skin pinching and calliper application.

During the ultrasound, there will be a cool gel placed along the quadriceps and the scanner will be lightly placed on the quad.

Blood tests may produce discomfort with blood drawn intravenously from the median cubital vein along the forearm. To ensure the safest environment for participants, blood will be drawn at LabTests® by their trained professionals. Any personal and health information will be kept under the privacy policy for confidentiality.

The stress questionnaires during the study may contain questions which could cause embarrassment.

How will these discomforts and risks be alleviated?

The risk of strength testing is probably less than that involved in your habitual training. You will have completed a physical activity readiness questionnaire in order to be included, and a first aid, CPR and AED certified researcher on site and spotters will be used during testing when necessary. The researchers are qualified professionals in the field of sports performance testing and are aware of and will be implementing all relevant safety procedures to ensure the minimisation of risk. The safety procedures include proper spotting technique for exercises that require it and ensuring correct technique is being performed of each exercise.

We will perform skinfold tests in a private room, with only a researcher, and the qualified research assistant in the room with you.

Lastly, the stress questionnaires will be taken at privately, and will be only identified by an encoded number with no personally identifiable information.

What are the benefits?

The main benefit from this study will be receiving professional dietary advice that is tailored to your sport. This advice could potentially help you in your future competition preparation. Also, the experience from this study will help to improve your ability to track your diet accurately. This will help with your personal and athletic development. You will also get exposure to understanding the experience of eating a diet that is outside of current recommendations.

You will undergo multiple skinfold testing by an accredited anthropometrist. This will help you understand your current percentage of body fat throughout the study and how diet can affect these measures.

Lastly, you will assist me in gaining my Masters in Sport and Exercise, which will help me further my career in the industry.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

To protect your privacy, your name will be removed from all data and replaced with a code on all materials used for data collection, analysis, reports and publications. During this research only the applicant and named investigators will have access to the data collected. The results of the study may be used for further analysis and submission to peer-reviewed journals or submitted at conferences.

What are the costs of participating in this research?

There will be no monetary costs during this study; all that we require from you is your time and effort, which we are very thankful for.

The following shows your time commitment throughout the 16-week study period.

Measure	Time Cost
An initial meeting will take place where you will complete the paper work (informed consent and health questionnaire) prior to participating in the full study. Also you will be instructed how to track your food intake, through Easy Diet Diary, and fill out a stress questionnaire.	1.5 hours
Food diaries	30 minutes per week
Stress Questionnaire	30 minutes per week
The skinfolds measurements and first interview in the week prior to the 8-week LCHF diet intervention	2 hours
An ultrasound scan of your quadriceps and strength	2 hours

assessment (Same week as above)	
The day after, you will be assigned a time to go to LabTests® to have your blood work taken	1 hour
The skinfolds measurements and second interview will run midway through the low carbohydrate high fat dietary intervention,	2 hours
A focus group and skinfolds measurements in the last week of the low carbohydrate high fat dietary intervention	3 hours
That same week, you will go through an ultrasound scan of your quadriceps and strength assessment	2 hours
At the end of the week, participants will be appointed their second blood test with LabTests®,	1 hour
During the 4-week 'return to normal' post intervention period, a final focus group with all participants	3 hours

What opportunity do I have to consider this invitation?

The final participant recruitment will begin in May to allow you time to think about whether you would like to be a part of this study. Following the recruitment phase, the participants will begin the 16 week intervention period at the start of June to allow enough to time for the data to be analysed.

How do I agree to participate in this research?

Please complete the health questionnaire and informed consent that you have been handed or emailed. You can either hand it to me in person or scan the forms and send them to me via email.

Will I receive feedback on the results of this research?

The results from the strength and skinfolds assessments will be given to you directly. After completion of data collection your personal results will be given to you and full disclosure of your dietary intake, from your food dairies, will be given to you from throughout the study. Also, once all the data has been analysed you will receive the results of the study, with the personal information protected for all participants.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Caryn Zinn, czinn@aut.ac.nz,* +64 (0) 9219999.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Simon Chatterton

simon_chatt@hotmail.com

Project Supervisor Contact Details:

Dr Caryn Zinn, Human Potential Centre: An AUT University research centre

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*

Appendix 3: Participant consent form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Consent Form

Project title: Does an eight week low carbohydrate high fat diet affect maximal strength performance, body composition and diet acceptability in competitive Olympic weightlifters and Powerlifters?

Project Supervisor: Dr Caryn Zinn

Researcher: Simon Chatterton

- O I have read and understood the information provided about this research project in the Information Sheet dated 26/05/2014.
- O I have had an opportunity to ask questions and to have them answered.
- O I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance.
- O I understand that identity of my fellow participants and our discussions in the focus group is confidential to the group and I agree to keep this information confidential.
- O I understand that notes will be taken during the focus group and that it will also be audio-taped and transcribed.
- O I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- O If I withdraw, I understand that while it may not be possible to destroy all records of the focus group discussion of which I was part, the relevant information about myself including tapes and transcripts, or parts thereof, will not be used.
- O I agree to take part in this research.
- O I wish to receive a copy of the report from the research (please tick one): YesO NoO

Participant's signature:...

Participant's name:...

Participant's Contact Details (if appropriate):

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 26th of May, 2014 AUTEC Reference number 14/112

Appendix 4: Health History Questionnaire

Personal Health Questionnaire

General Information

Name:

Height:

Weight:

Age:

Contact Number:

Address:

Email:

Current Occupation:

Name of your General Physician:

Smoker: Y/N

Medical Information

Do you currently have (please tick one of the boxes):

	Yes	No
Hypertension		
Asthma		
Diabetes		
Vertigo		
Dizziness		
Kidney Disease		
Any Heart Trouble		

Appendix 4 continued: Health history questionnaire

Do you have any family history of the following:

	Yes	No
Hypertension		
High Cholesterol		
Diabetes		
Stroke		
Early Death		
Heart Attacks		

Any other family problems…

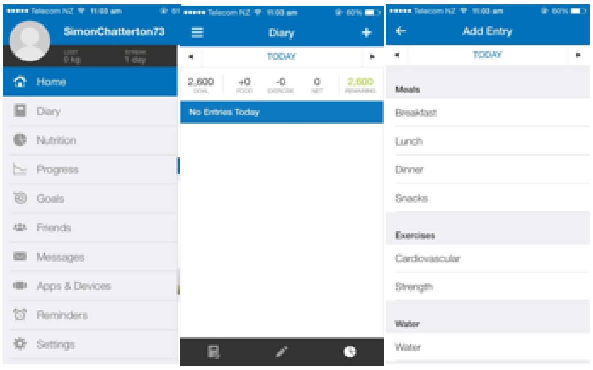
- Do you suffer from any mental health diseases? If yes please identify
- Have you taken or currently taken any prescribed medication for your GP?
- Is there any other medical condition that has not already been identified for the past question? If yes please explain

Appendix 5: My Fitness Pal® handbook

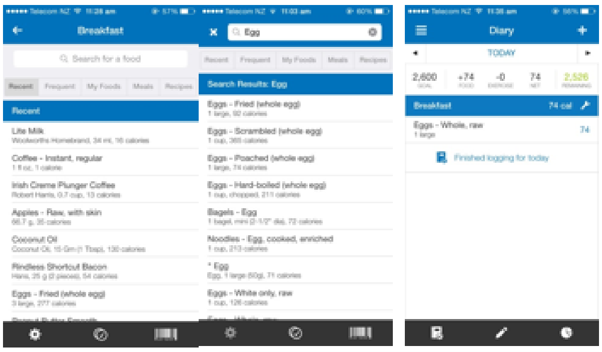
My Fitness Pal Handbook

The following is a simple handbook to My Fitness Pal. This will provide you with basic information for you to record your daily food intake with accuracy. Not only will this bring you to a basic skill level but once you have had more time working with this application, you will become more efficient in recording.

Logging in food:



After signing into the application you are then able to begin recording your food. First select 'Diary' (Picture 1) to access your daily food diary. You can select the plus (+) sign in the top right hand corner to add a food item (Picture 2). Then select the category of the meal i.e breakfast (Picture 3).



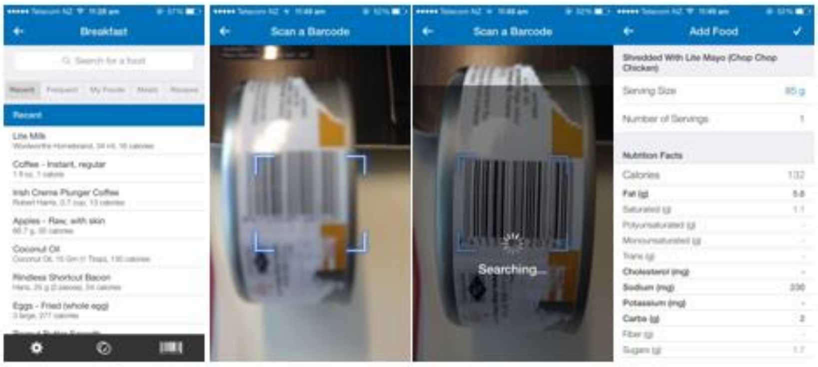
myfitnesspal

Appendix 5 continued: My Fitness Pal Handbook

In the top of the screen underneath the 'Breakfast' title there is a search bar where you can type in your food item. For this example, I typed in 'egg', My Fitness Pal then draws upon its food database (Picture 2). Find this most realistic food item on this list. For me, I found the item the best suited my type of egg which was a fried egg (Picture 3). Also, when choosing the correct item make sure you select an accurate serving size. **It is important to make sure the nutritional information listed below in Picture 3 is accurate. If you are unsure, use another application such as Easy Diet Diary or Google to see if the food item matches up correctly.** The serving size can be adjusted when you select it as well as number of servings, i.e "1 large" with "one serving".

Once you have found your food item select the tick on the top right hand corner (Picture 3) to save this food item into your food diary for the day. Your food diary home screen should look similar to picture 4 where the food is properly recorded into your food diary.

Scanning Food:

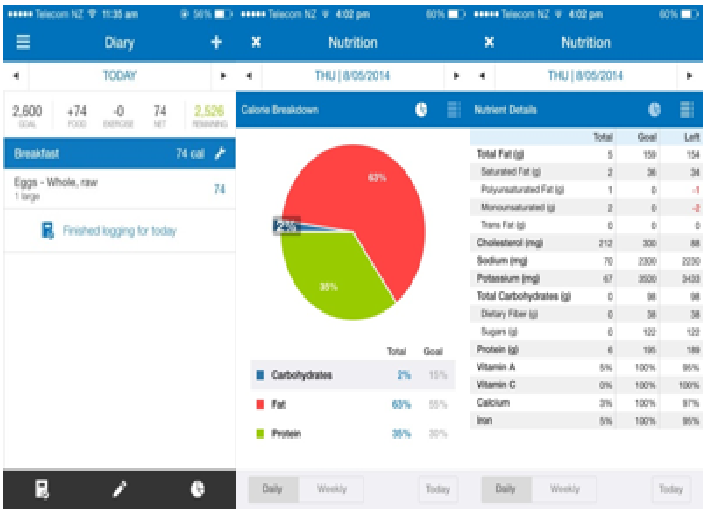


When scanning food items there is a barcode button that will allow you to scan items in the bottom right hand corner (Picture 1). This will come up with the camera mode and blue framing tool for the barcode of the food item (picture 2). Make sure the barcode is clearly shown and hold the camera still so that it can focus on the barcode. If the food item is registered in the My Fitness Pal food database then it should come up with the selected food item (Picture 3). **Check the serving size** for big cans of food such as tuna, where there are actually two servings per can even though you may use the whole can in one meal.

myfitnesspal

Appendix 5 continued: My Fitness Pal Handbook

Checking your 'Marcos'

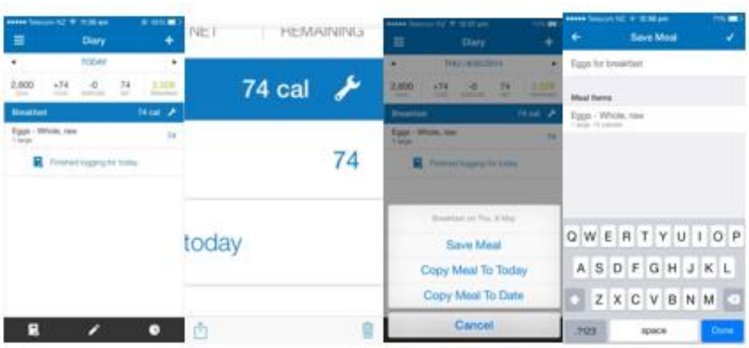


A cool way to monitor your carbohydrate intake is using the pie graph and small summary sheet tool. This is found in the bottom right hand corner in picture one. By selecting this, you will bring up a pie graph of your macro nutrient breakdown, as seen in picture two. Blue represents carbohydrate, red represents fat and green represents protein. You can find the exact numbers in the next spreadsheet by selecting the icon next to the small pie graph along the calorie breakdown blue strip in picture two. This is called 'nutrient details', which provides a small summary of your daily macro and micronutrients. For your own observations it is good to keep an eye on your carbohydrate once you are on your low carbohydrate high fat diet.

myfitnesspal

Appendix 5 continued: My Fitness Pal Handbook

Creating meals

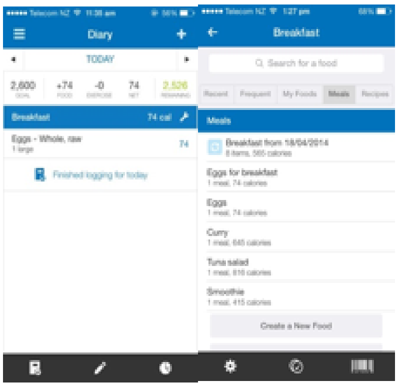


Once you food items are saved in to your diary, you can now create meals. Select the wrench tool on the right below the calorie counter (Picture 1 and 2). This will give you the options of 'Save Meal', 'Copy Meal to Today' and 'Copy Meal to Date' (Picture 3).

If this the first time logging a meal, and this is a regular meal that you would eat, 'Save Meal' will log your meal into the database for you to use. Picture 4, shows the details of your meal; select the tick button in the right hand corner in order to save the meal.

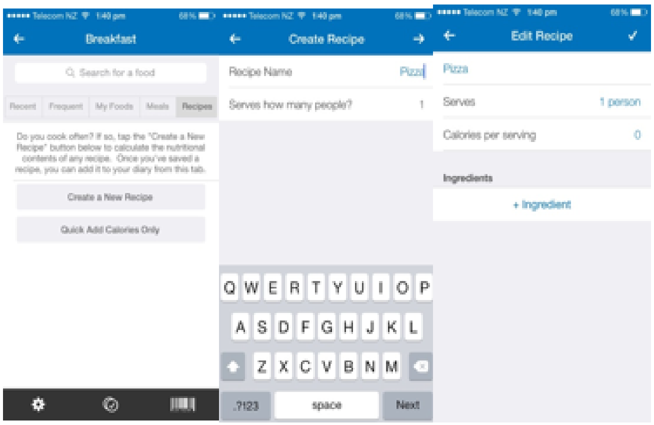
If you know you are going to have the same meal at another date, 'Copy Meal to Date' can add this meal to any future date you choose. This will make food recording less time consuming as you may often double up in meals during a week.

Appendix 5 continued: My Fitness Pal Handbook



Lastly, when selecting a meal use the same '+' icon as when you select food (Picture 5); where there will be a selection panel with 'Recent' 'Frequent' 'My Foods' 'Meals ' Recipes'. Choose 'Meals' and your meals that you have saved will be ready to be used from there (Picture 6).

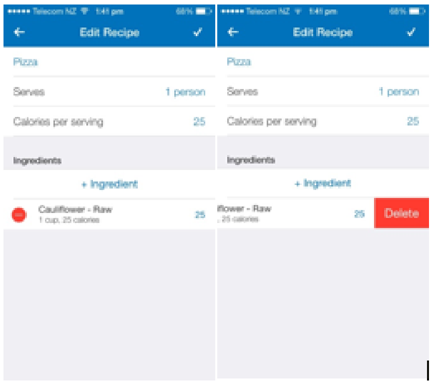
Developing Recipes



If you prefer making your own foods, like cauliflower pizza bases, there is a tool for you to create your own recipes. This is along the same tool bar when you want to add foods to your diary (Picture 1). To get started into a recipe select 'Create a New Recipe'. Once you have selected 'Create a New Recipe' it will come up with the initial recipe screen (shown in Picture 2). First type in a title for the recipe in the first bar, here I have put 'Pizza'. You can alter the servings to fit your needs, then select the arrow pointing right (top right corner of Picture 2). Now create your own recipe by searching for the raw ingredients (Picture 3). To

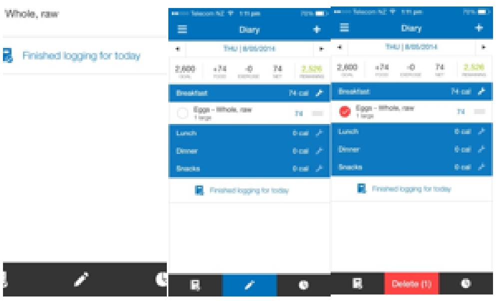
Appendix 5 continued: My Fitness Pal Handbook

search for the ingredients select the '+ Ingredients' icon, and this will give you a search bar to enter any ingredient and to find it in the My Fitness Pal database. Once you have created your recipe, select the tick in the right hand corner to save (Picture 3).



If you have any ingredients you have incorrectly selected, each ingredient will have a red minus circle next to them. Select this red minus circle; it will then come up with an option to delete the item (Picture 2). Select this red delete icon to delete the item off the recipes ingredient list.

Deleting foods



If you have made a mistake, there is a simple way of deleting the foods. In the initial food diary page, there is a pen icon in the bottom middle (Picture 1). Select this pen icon; this will bring up a small empty circle next to each food item (Picture 2). Select the circle and at the bottom of the screen will be a 'Delete (1)', select this icon which will delete the item of your food diary.

myfitnesspal

Appendix 6: Daily Analysis of Life Demands of Athletes

Name____________________ Date____________________

Daily Analyses of Life Demands for Athletes (DALDA) Questionnaire
Part A: Record stress in your life circle a, b, or c (a = worse than normal, b = normal, c = better than normal)

1. a b c Diet
2. a b c Home Life
3. a b c School/college/work
4. a b c Friends
5. a b c Sports Training
6. a b c Climate
7. a b c Sleep
8. a b c Recreation
9. a b c Health

Total "a" responses:____ Total "b" responses:____ Total "c" responses:____

Part B list possible causes of stress circle a, b, or c (a = worse than normal, b = normal, c = better than normal)

1. a b c Muscle Pains
2. a b c Techniques
3. a b c Tiredness
4. a b c Need for rest
5. a b c Supplementary Work
6. a b c Boredom
7. a b c Recovery Time
8. a b c Irritability
9. a b c Weight
10. a b c Throat
11. a b c Internal
12. a b c Unexplained aches
13. a b c Technique Strength
14. a b c Enough Sleep
15. a b c Between Session Recovery
16. a b c General Weakness
17. a b c Interest
18. a b c Arguments
19. a b c Skin Rashes
20. a b c Congestion
21. a b c Training Effort
22. a b c Temper
23. a b c Swelling
24. a b c Likability
25. a b c Runny Nose

Total "a" responses:____ Total "b" responses:____ Total "c" responses:____

Appendix 7: Your Low Carbohydrate High Fat (LCHF) Handbook

Page | 1

Your Low Carbohydrate High Fat (LCHF) Handbook

Created by: Simon Chatterton and Dr Caryn Zinn RD

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

The basis of your low carbohydrate high fat diet

Introduction: What's the diet all about?

A low carbohydrate high fat (LCHF) diet has become increasingly popular in both the general public and in athletes. It is considered a way of consuming nutrient dense whole food which can regulate blood glucose levels and facilitate weight loss. The rationale behind the reduction in carbohydrate is that this allows body fat to be utilised as a fuel source, and behind the increase in fat is that fat keeps you satiated (full) for longer.

How does this relate to Olympic weightlifting/ Powerlifting?

A LCHF diet could be a favourable tool to change body composition (lose fat, maintain lean muscle) rather than using rapid weight loss methods. Scientific evidence shows that when manipulating the diet for a short period of time, (i.e., 4 to 8 weeks) fat loss can be achieved with maintenance of lean muscle mass and strength. In the sports of Olympic weightlifting and powerlifting this could result in an increase in your Wilks or Sinclair score during competition. We believe that LCHF fat diet can result in better competition preparation.

Thinking differently about your method of dropping body fat by restricting carbohydrate to between 1 and 1.5g per kg of bodyweight...

Some general guidelines about this approach are as follows:

- You will be eating plenty of non-starchy vegetables.
- Each meal will have a good portion of fat.
- You will eat the same amount of protein that you currently eat during the day.
- Use the dietary analysis programme (computer or phone application) My Fitness Pal to track for your food intake.
- You will be cooking with olive oil, coconut oil, or butter. Add flavoured oil (i.e. avocado / nut) oils to salads.

How you might feel in the initial stages of the diet:

When restricting carbohydrate in your diet, your body needs time to adjust. While the level of carbohydrate restriction is not as severe as a ketogenic diet (i.e., very low amounts of carbohydrate), you may still experience *initial symptoms*, such as fatigue during training, grumpiness and/or lack of concentration, which should disappear after the first week (or

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

two). You may also experience some initial frustration of not being able to eat foods that you would usually eat. We will give you as much support as possible to help you through this stage if you experience any of these symptoms.

Here is how you might want to approach meal times at home through carbohydrate, fat and protein:

Carbohydrate:

- You are able to eat any vegetable that grows above the ground. These are lower in carbohydrate. If you have any doubt, check your My Fitness Pal.
- To be most cost-effective when buying vegetables, shop at a local vegetable store, look for sales and special deals, and choose frozen options.
- Spread your carbohydrate intake throughout the day. Consume 25% of your daily carbohydrate an hour or two before training and 25% post training.
- A maximum of one to two pieces of fruit is recommended; try to aim for lower sugar fruits such as any type of berry.
- Limit artificially sweetened foods, but you can use stevia (natural sweetener) in your cooking.

Fat:

- Add enough fat to the meal (as little or as much) to keep you satiated (full) until the next main meal. Avocado and coconut are great source of fat to use in meals.
- A small handful of nuts can be used as a snack. Make sure you buy either raw or non-flavoured nuts.

Protein:

- Most types of meats. Canned salmon, sardines and tuna are good low cost options for lunches. Watch out for mince, sausages, and hamburger patties that have been processed as they sometimes have added carbohydrate. The same caution applies to cured meats such as bacon and ham, as sugar or honey can be used in the curing process.
- For dairy products, cheeses are encouraged, however limit milk intake due to its high carbohydrate content. An alternative option to regular yoghurt, is plain unsweetened high fat Greek yoghurt. Use full fat varieties where possible.

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Table 1: Examples of foods with various protein, carbohydrate and fat amounts.

Protein (with grams of protein)	Low Carbohydrate Vegetable/ fruit (with grams of Carbohydrate)	Fat (with grams of fat)
Salmon (23 grams per 100g)	Carrots 1 Medium (5.6 g)	Coconut Oil
Eggs (One large egg=6.3g)	Broccoli 1 cup (5.8g)	Butter
Egg white (1 cup=26.5 g)	Cauliflower 1 cup (5.1g)	Extra Virgin Olive Oil
Chicken (31g per 100 grams)	Cabbage 1 cup (5g)	Avocado Oil
Steak (22g per 100 grams) (Rump Steak)	Tomato 1 medium (5g)	*Almonds
Cheese (26.8 per 100 grams) (Mild)	Eggplant 1 cup (6.6g) A Slice (2.2g)	*Peanuts
Lamb Chops (24g per 100g)	Spinach 1 cup (1.7g)	*Brazil nuts
Lamb Mince (17.6 per 100g)	Avocado 1 half (0.6g)	Avocado: Half: 25.6g
Beef Mince (20.2g per 100g)	Blueberries Half a cup (8.0g)	Olives
Tuna (Canned) (17 g per 100g)	Mixed Berries Medium Size: 0.3g	Pesto 1 tablespoon: 26g
	Mushrooms ½ cup (0.2g)	
	Olives (black/green) ½ cup (2.3g)	
	Onion ½ cup (2.9g)	
	Pumpkin 100g (6 g)	

*consume nuts in moderation, one to two servings per day.

There are plenty of other options outside of these lists; to find the macronutrient breakdown log the particular food with the portion size into My Fitness Pal.

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Limit these foods:

Potatoes, kumara, corn and any other starchy vegetables.

Avoid these foods:

Rice, pasta, bread, cereals, muesli bars, crackers, couscous, sugary drinks (includes sports drinks) and anything high in carbohydrate that you come across.

Eating outside of the home, how to go about it:

You may think it is near impossible to go out for a meal while eating a LCHF diet, but most cafes and restaurants do have low carbohydrate options.

- Cafes commonly provide big breakfast or egg options. Sides of vegetables such as spinach or mushrooms are always good.
- Watch out for breakfast sausages as they might be high in carbohydrate.
- Coffee with little to no milk, such as espresso. You could always order milk or cream on the side.
- Green salads with olive oil / balsamic dressing.
- **Try to avoid fast food restaurants**
- Bun less option for burger places. Burger fuel has a 'low carbonator' burger.
- Lots of dressings and sauces have sugar added for extra flavour. Ask for the ingredients for the dressing/sauces or otherwise avoid.
- **Avoid deep fried, battered foods.**
- **Avoid gravy.**
- Don't be afraid to ask for what you want. You are the one paying for it.
- Don't believe everything you read: the nutritional information isn't always correct.
- Salad options are usually good; however avoid croutons, obvious CHO additions (pasta/rice/ couscous) and check the dressing (see above).

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Low Carbohydrate High Fat meal ideas

Breakfast Idea

Bacon and Eggs with veggies

2 pieces of Bacon (50grams Shortcut Bacon)

2 large Eggs (Fried)

1 tablespoon of Coconut Oil

2 tomatoes (medium size)

1 cup of button mushrooms

1 cup of spinach

Salt, pepper

Method: Add coconut oil to hot pan; let the coconut oil melt before adding the bacon and eggs. Once they are cooked, place the vegetables in to the pan to sauté in the cooking juices before serving hot with the bacon and eggs.

Fat	Carbohydrate	Protein
39.3grams	10 grams	28.9grams

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Breakfast Idea (#2) Berry Smoothie:

1 cup of mixed frozen berries

1 cup of natural unsweetened Greek Yoghurt

½ cup of full fat milk

1 scoops of Low Carbohydrate protein powder

1 tablespoon of peanut butter

Method: Add all ingredients in to a blender or food processor and blend until you have your preferred consistency. The milk can be substituted for unsweetened almond milk for a lower carb content.

Fat	Carbohydrate	Protein
31.1g	11.4g	26.1g

Breakfast Idea (#3) Yoghurt, nuts and berries, <u>an alternative to cereal</u>

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Natural unsweetened Greek Yoghurt

½ cup of Coconut flakes

20 grams almonds (chopped)

20 grams any other variety of nut (macademia, walnut, hazelnut)

1 scoop of low carbohydrate protein powder

1 cup of mixed frozen berries

Method: Add natural unsweetened Greek yoghurt, coconut flakes and low carbohydrate protein powder in to a bowl. Chop almonds and the other nuts into small chunks, and then add to the yoghurt mixture (you could always roast these prior). Lastly, heat frozen berries up in the microwave before pouring on top of the yoghurt mixture.

Fat	Carbohydrate	Protein
68.4g	23.4g	32g

Breakfast idea (#4): Veggie mmelette with bacon

http://www.whatscookingwithruthie.com/wp-content/uploads/2012/08/Spinach-and-Bacon-Omelette1.jpg

3 large eggs

2 tablespoons of full fat cream

50grams of Edam cheese

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Salt and pepper

Filling:

2 tomatoes

1 cup of spinach

2 rashers of bacon

5 mushrooms

Method: Whisk together 3 eggs, 2 tablespoons of full fat cream and grated cheese in a small bowl. Add coconut oil to a frying pan, and then add the whisked ingredients once the coconut oil has melted. Fry one side first before adding the filling in to the omelette and folding.

Fat	Carbohydrate	Protein
49.9g	11.3g	43g

Breakfast idea (#5) High Protein High Fat Pancakes

1 serving of Protein powder

½ a cup of Eggs whites (Zeagold)

2 tablespoons coconut milk

A dash of Vanilla extract

1 tablespoon of coconut oil to pour on pancake

Method: Mix together all ingredients in a small bowl. Add coconut oil to a heated frying pan. Place large spoonful of the mixture on to the pan, wait until the side on the pan is cooked before flipping the pancakes to the other side. Serve with melted coconut oil or butter to your taste.

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Fat	Carbohydrate	Protein
17.2g	2.2g	35g

Lunch Ideas

Lunch Idea (No. 1): Tuna with stir fry vegetables

1 ½ cups spinach

1 cup × Stir Fry: Cabbage (1 cup), carrot (½), mushrooms (3 medium), broccoli (1 cup), capsicum (½ medium sized)

1 tablespoon coconut oil

1 tablespoon Soy Sauce

1 teaspoon chopped garlic

1 big can (186 grams) tuna (lemon pepper flavour)

Method: for stir frying the vegetables, add coconut oil to frying pan or wok. Then add any type of low carbohydrate vegetable, for this example I used cabbage, broccoli, mushroom, carrot and capsicum. After the vegetables have welted down, add soy sauce and chopped garlic for flavour. If you want to, add a teaspoon of chilli powder for some heat. Serve it hot or reheat another time. Add the can of Tuna and fresh spinach for a quick wholesome meal.

Fat	Carbohydrate	Protein
82.4g	26g	49g

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Lunch Idea (#2) Chicken, Eggs and avocado salad

100g of shredded chicken

2 boiled eggs

1 tablespoon avocado oil

1 tomato

1 tablespoon Balsamic vinegar

Any variety of salad lettuce (spinach, iceberg, mesclun), 1 medium tomato, 1 grated medium carrot and courgette, ½ medium capsicum and a cup of steamed broccoli.

Method: N/A

Fat	Carbohydrate	Protein
26.6g	17g	31.6

Lunch Idea (#3) Stuffed Peppers

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

2 whole capsicums (cut the top, hollow them out for stuffing)

150 grams of mince

1 tablespoon of coconut

1 onion

2 medium carrots

Spices and Herbs

50 grams of cheese

Method: Hollow out two whole capsicums by cutting a medium hole from the top of the capsicum and take out the core and seeds. Rinse hollowed capsicums in water to remove the remainder of the seeds. Fry mince, onion, carrot and spices and herbs in coconut oil before stuffing the pepper with the filling. Add cheese to the top of the filled capsicum before putting in the oven at 180°, cook until cheese has melted.

Fat	Carbohydrate	Protein
42.4g	21g	43.3

Lunch Idea (#4): Salmon and pesto with grilled tomato and spinach

1 large can of salmon

1 serving of pesto

1 tablespoon of avocado oil

2 medium sized tomatoes

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

1 handful of Mesclun Salad

Salt and pepper

Method: Empty can of salmon and a serving of pesto into a small bowl, mix together thoroughly. Grill or pan fry tomatoes with salt and pepper. Add the ingredients to any type of salad leaves.

Fat	Carbohydrate	Protein
51.4g	15g	30.4

Lunch Idea (#5): Peanut Chicken with Steamed Broccoli and Cauliflower

1 Chicken Breast sliced thinly (150grams)

Sauce

1 tablespoon of smooth peanut butter

1 tablespoon of soy sauce

Chilli powder (add to your preference)

1 medium onion (fried with coconut oil and added to sauce)

1 teaspoon of garlic

1 teaspoon of ginger

Steamed vegetables

1 cup of broccoli

1 cup of cauliflower

Method: In a frying pan add a tablespoon of coconut oil and one finely chopped onion. Let coconut oil melt and onions brown before adding a tablespoon of peanut butter (smooth or chunky). Once the peanut butter has melted, add the additional ingredients to the sauce and bring it to a simmer.

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Cook chicken separately before adding peanut sauce. Finish by steaming broccoli and cauliflower for an easy lunch.

Fat	Carbohydrate	Protein
26.9	25g	51.4

Dinner ideas

Dinner idea (# 1) (three servings): Lettuce leaf wraps with salsa

3 big leaves of Lettuce

400g ground mince (beef or lamb)

1 tablespoon of avocado oil

1 onion

1 tablespoon minced garlic

1 table spoon Soy Sauce

Spices and herbs to taste (i.e chilli)

Salsa:

2 tomatoes

1 medium capsicum

1 medium Red onion

½ Avocado

Lemon Juice

1 tablespoon of avocado oil

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Parsley and mint to taste

Method: Cook mince, onion and herbs and spices in a frying pan until gold brown. In a separate bowl, add finely chopped tomato, capsicum, red onion, and half an avocado. Then add lemon juice, avocado oil and fresh parsley and mint to the mixture. Tear off large lettuce leaves for your wrap to add in the mince and salsa mixture.

Fat	Carbohydrate	Protein
25.2g	10g	34g

Dinner idea (#2): Frittata (two servings)

2 onions

2 tomatoes

2 cups chopped spinach

2 tablespoons of full fat cream

3 rashers of bacon

5 eggs

salt and pepper

1/4 cup grated Edam/cheddar cheese

Method: Whisk together 5 eggs, 2 table spoons of full fat cream and salt and pepper in a bowl. Cook rashers of bacon, spinach and onions in a frying pan before adding in the egg mix. Place the frying pan in the preheated 180° oven for 10-15 minutes then sprinkle cheese on top before putting the frittata back in the oven for an additional 5-10 minutes or until it looks ready.

Fat	Carbohydrate	Protein

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

39.8g	16.5g	30.7g

Dinner idea (#3) Chicken Curry with Cauliflower Rice (2 servings)

6 Chicken drumstick

1 serving Green Curry Paste (Valcom Asian)

1 can of coconut milk

2 onions

1 can of Coconut milk

A head of cauliflower

1 tablespoon of coconut oil

*add some additional vegetables to increase your carbohydrate intake.

Curry Sauce with Chicken:

Method: Add onions and coconut oil to a hot frying pan. Once the onions are browned add the chicken drumsticks. Cook the drumsticks almost all the way through before adding the green curry paste and can of coconut milk to the pan for the sauce. Simmer until the drumsticks are cooked all the way through. For the cauliflower rice, chop the cauliflower in to florets before placing it in a food processor and blend until it turns into a 'rice' like consistency. Then to cook the 'rice' fry in a separate pan in coconut oil.

Fat	Carbohydrate	Protein
48.7g	20.7g	43.4g

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Dinner Idea (#4) Eggplant burgers (with halloumi) (Vegetarian option) :

2 servings of (150 grams) Halloumi cheese

1 table spoon of Avocado oil

4 thick slices of Eggplant

1 medium Tomato

1 cup of Spinach

2 servings of Hummus

Salt and pepper

*add a green salad with avocado or coconut oil for additional fat

Method: Cut eggplant in large slices. Before grilling the large slices, add olive oil, salt and pepper to bring out the flavour. Pan fry thick slices of halloumi in avocado oil until both sides are well cooked. Once both ingredients are cooked, build your own burger with spinach, tomato and hummus or other low carbohydrate vegetables you decide.

Fat	Carbohydrate	Protein
57.4g	16.7g	37g

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Dinner Idea (#5) Steak with Cauliflower mash:

Lean Steak (Rump etc) (for this example, I used 250gs of steak)

Cauliflower Mash (2-3 servings)

8 Medium-sized head of cauliflower

3 roasted garlic cloves

1 teaspoon fresh thyme leaves

2 tablespoons of coconut oil

1 teaspoon fresh chives, chopped

salt and pepper

*add a green salad with avocado or coconut oil for additional fat

Method: To make cauliflower mash, cut the head of cauliflower into small florets and boil them in salted (1 teaspoon) water. Once the cauliflower is cooked, drain water and pour cooked florets in to a food processor. Blend and slowly add one tablespoon of coconut oil to give the cauliflower mash smoothness. Blend the mixture further before adding an additional tablespoon of coconut oil. Finally cook steak to your preference, do not throw away the cooking juices, pour it over your steak once it is cooked for the additional fat.

Fat	Carbohydrate	Protein
27.1 g	11g	46.8g

Appendix 7 continued: Your Low Carbohydrate High Fat (LCHF) Handbook

Snack ideas

- 30g cheese
- 1/3 cup nuts (eg. almonds)
- 1-2 eggs
- Vegetables, dipped in guacamole / pesto / almond butter
- 5-10 green/black olives
- 50g beef jerky/biltong (cured without sugar; check packet)

Sweet treats

These contain no more than 5g CHO per serve.

- Chocolate pudding: 2 tbsp double cream, 1 tbsp unsweetened cocoa and 1 sachet Splenda/ 1/2 tsp stevia. Blend together until it has consistency of soft ice cream.
- Handful of berries with coconut cream.
- Mocha pudding: as above and add 1 tablespoon of instant coffee.
- Raspberry mousse: make up a Weight Watchers jelly and partially set in fridge. Whip 120ml (1/2 cup) cream and blend into jelly. Return to fridge until set. Serves 4.

For more LCHF recipe ideas see the following link http://www.pinterest.com/carynzinn/

Appendix 8: Study recruitment flyer

Appendix IV: Poster for recruitment

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

Does an 8 week low carbohydrate high fat diet affect maximal strength performance, body composition and diet acceptability in competitive Olympic weightlifters and powerlifters?

Contrary to belief, eating fat will not make you fat, rather eating excess calories can result in fat gain. In fact, there may be benefits when replacing a portion of your calories from carbohydrate, with calories from fat. In strength athletes, there is evidence that this can improve health markers, body composition and doesn't appear to negatively affect performance in the short term.

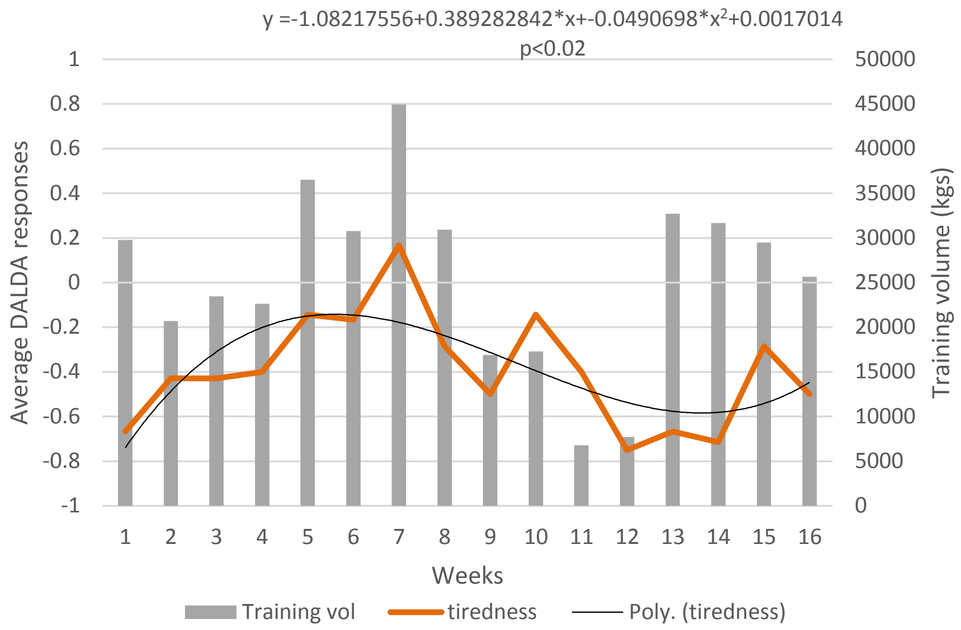
This study could be of benefit to you if you are competitive Olympic weightlifter or powerlifter who meets the following criteria;

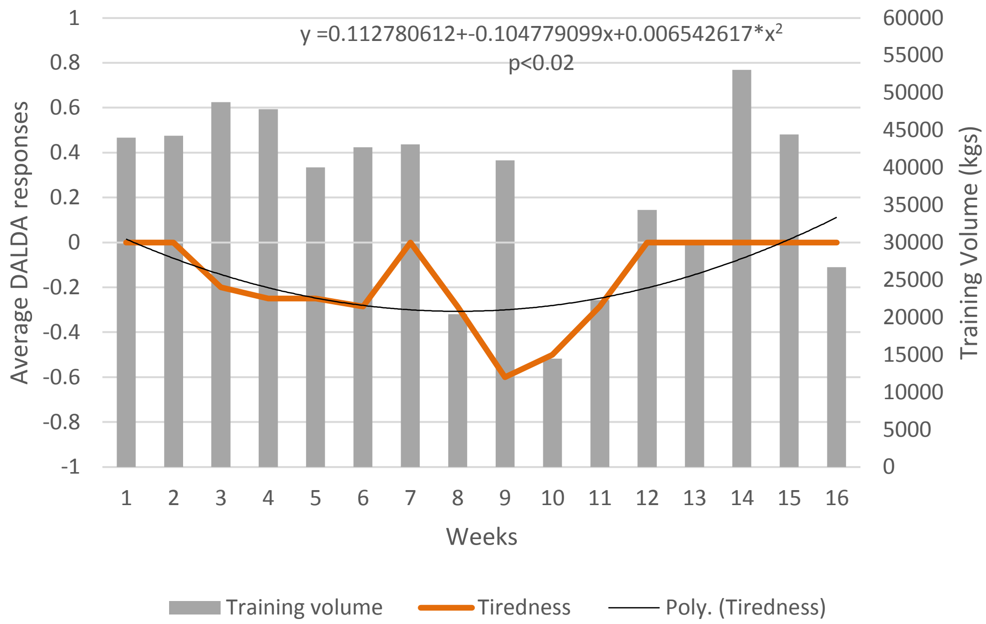
- **A 'C class' (or greater) Olympic weightlifting as per the Olympic Weightlifting New Zealand standards or,**
- **A 'bronze class' (or greater) powerlifter as per the New Zealand Powerlifting Federation standards.**
- **Aged between 21-35 years**
- **A minimum of two years of competitive experience.**
- **Healthy and injury free**

-This is an opportunity for you to receive free dietary consultation and analysis from a registered dietician, and multiple body fat testing during the study.

If you are interested in being a participant in this study or have any further questions regarding the study, please email Simon at simon_chatt@hotmail.com

Appendix 9: Graphical representation of 'tiredness' response trend for Participants 1 and 5 with training volume.





Appendix 10: Graphical representation of 'need for rest' response trend for Participants 1, 2, and 3 with training volume.