The Impact of Eating behaviours and Training Practices on Health in Female Physique Athletes: A Multi-Method Exploration

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ABBREVIATIONS

Alb, Albumin

ALP, Alkaline Phosphatase

ALT, Alanine Aminotransferase

ANOVA, Analysis of Variance

AU, Arbitrary units

BCAA, Branched-chain amino acids

BM, Body Mass

BRUMS, Brunel Mood Scale

BIL, Bilirubin

C, cortisol

Ca^+, Calcium

CHO, Carbohydrates

CHOL, Total Cholesterol

Cm, Centimetre

CI, Confidence Intervals

CK, Creatine Kinase

CRE, Creatinine

CRP, C-reactive protein

CV, Coefficient of Variation

D, Days

DE, Disordered Eating

DXA, Dual X-ray Absorptiometry

E_2, Oestradiol

EA, Energy availability

EAT, Eating Attitudes Test - 26 items

ECW, Extracellular Water

ED, Eating Disorder

EEE, Exercise Energy Expenditure

EI, Energy Intake

ES, Effect Size

Exp, Experienced

FE, Ferritin

Fig, Figure

Fit, Fitness

FFM, Fat-free Mass

FM, Fat Mass

FP, Female Physique

FSH, Follicle-Stimulating Hormone

FT_3, Free Triiodothyronine

FT_4, Free Thyroxine

G, Gram

GH, Growth Hormone

HDL-C, High-Density Lipoprotein Cholesterol

HPO, Hypothalamic-pituitary-ovarian

HPT, Hypothalamic-pituitary-thyroid

HR, heart rate

I, Insulin

IFBB, International Federation of Bodybuilding and Fitness

ICW, Intracellular Water

IFBB, International Federation of Bodybuilding and Fitness

IGF-1, Insulin-Like Growth Factor

IOC, International Olympic Committee

IPED, Image and Performance Enhancing Drugs

ISE, Ion Selective Electrode

ISAK, International Society for the Advancement of Kinanthropometry

K, Potassium

KG, Kilograms

Kcal, Kilocalorie

LBM, Lean Body Mass

LEA, Low Energy Availability

LEAF-Q, Low Energy Availability in Females Questionnaire

LFT, Liver Function Tests

LDL-C, Low Density Lipoprotein Cholesterol

LH, Luteinising Hormone

Nov, Novice

Mg, Magnesium

MMA, Mixed martial arts

PHOS, phosphate

PNa^+, Plasma Sodium

PRL, Prolactin

PRO, Protein

PROG, progesterone

PSQI, Pittsburgh Sleep Quality Index

PWCM, Pathogenic weight control method

RED-S, Relative Energy Deficiency in Sports

RMR, Resting Metabolic Rate

RMR_{meas}, Resting Metabolic Rate Measured

RMR_{pred}, Resting Metabolic Rate Predicted

$RMR_{ratio,}$ Resting Metabolic Rate ratio

RPE, Rating of Perceived Exertion

RWLQ, Rapid Weight Loss Questionnaire

RWLS, Rapid Weight Loss Score

SD, Standard Deviation

SENr, Sport and Exercise Nutrition Register

Serum total 25(OH)D, Total 25-hydroxyvitamin D

SHBG, Sex Hormone Binding Globulin

sRPE, Session Ratings of Perceived Exertion

T, Testosterone

TEI, Total Energy Expenditure

TBW, Total Body Water

TEE, Total Energy Expenditure

TEI, Total Energy Intake

TEM, Technical Error of Measurement

TG, Triglyceride

TL, Training Load

TV, Training Volume

TMD, Total Mood Disturbance

TP, Total Protein

The Triad, The Female Athlete Triad

U, Urea

U_{usg}, Urine Specific Gravity

U_{osm}, Urine Osmolality

WADA, World-Anti-doping Agency

WK, Weeks

$\sum 8SKf$, Sum of 8 skinfold sites

ABSTRACT

Female physique (FP) athletes are judged subjectively on aesthetic appearance and posing ability. Typically, an annual season is divided into an off-season (which can last a number of months to even a year) and an in-season which involves a pre-competition phase (approximately 12-24 weeks), competition week (normally the final 7 days prior to competition) and a recovery phase. Engaging in prolonged and/or acute weight loss practices can induce physiological and psychological strain that may result in negative long-term consequences. The profile of weight history and dieting behaviours used by FP athletes is still largely unknown. Additionally, few studies have assessed the physiological, psychological and social health implications involved in physique sports across different phases of the annual season. Therefore, the main aim of this thesis was to investigate the impact of eating and training practices on health implications in FP athletes. Understanding these aspects will promote awareness regarding the requirements to be a FP athlete, whilst also ensuring physique athletes' health and welfare is optimal.

Study 1 (Chapter 3) investigated the weight loss history, practices and influential sources of information about dieting during the pre-competition phase in 158 FP athletes stratified by division and experience level. It was aimed to determine the relationship between experience level and division, and weight management practices. This is crucial for determining whether there is a need for tailored awareness and targeted education for FP athletes with varying levels of experience competing in different divisions. Eating attitudes and behaviours were assessed to identify whether athletes were at risk of developing an eating disorder. Using a cross-sectional research design, FP athletes completed an anonymous online self-

reported survey consisting of the Rapid Weight Loss Questionnaire and Eating Attitudes Test-26.

Athletes reported using chronic gradual dieting (94%), food restriction (64%) and excessive exercise (84%), followed by acute body water manipulation via water loading (73%). There were no associations between division or experience and these practices. Nevertheless, division significantly impacted absolute ($P<0.01$), and relative ($P=0.03$) weight regain with Figure athletes (a specific division within female physique sports) showing the greatest increase in body mass (5.5%) 7-days following competition. Overall, 37% of FP athletes were at risk of developing an eating disorder, mirroring rates in other leanness-focused elite sports (35% out of 61 athletes (Kong and Harris, 2014), but higher than the general population (3-10% out of 2444 male and female individuals) (McEnery et al., 2016). Additionally, 42% of FP athletes used two pathogenic weight control methods (Laxatives, diet pills and diuretics use and binge eating) with 34% of Figure novice athletes (≤1 year of competition experience) indicating binge eating at least once a week. The coach (89%) and other athletes (73%) were identified as key influences on athletes' dieting practices and weight loss. Although most female athletes acquire their body composition using acute and chronic methods, the prevalence of athletes identified with disordered eating symptoms and engaging in pathogenic weight control methods is concerning.

Having quantified a high prevalence of the use of gradual dieting, food restrictions and excessive exercise during pre-competition in study 1 (Chapter 3), study 2 (Chapter 4) aimed to document self-reported dietary intake, training practices and psychological states during the pre-competition phase in FP athletes. In an observational study design, nine free-living natural (*i.e.*, drug-free) FP athletes completed a three-day weighed food diary, training diary and perceived well-being and mood states questionnaires for three days at three separate time-points (-12 weeks, -4 weeks and -1 week) prior to competition.

A reduction in BM (60.9 ± 8.1 kg to 55.6 ± 8.9 kg, Δ5.3kg ± 3.4; $P < 0.01$; effect size [ES] = 0.59, 95% CI= -0.36 to 1.53) coincided with reductions in absolute mean energy intake (1738 ± 236 $kcal.day^{-1}$ to 1379 ± 285 $kcal.day^{-1}$, P=0.03; ES=1.31, 95% CI= 0.29 to 2.32), protein intake (166 ± 14 $g.day^{-1}$ to 137±30 $g.day^{-1}$; P=0.02; ES=1.20; 95% CI= 0.20 to 2.20), and fat intake (48.7 ± 14.5 $g.day^{-1}$ to 35.5 ± 17.85 $g.day^{-1}$, P=0.03; ES=0.77; 95% CI= -0.19 to 1.73), with no changes in carbohydrate intakes or any nutrient relative values from -12 weeks to -1 week pre-competition (P>0.05). Macronutrient distribution did not differ between time-points (P>0.05), except for energy intake per meal between -12WK (188.7 ± 142.6 $kcal.day^{-1}$and -1WK (152.5 ± 134.1 $kcal.day^{-1}$; 95% CI=1 to 71 $kcal.day^{-1}$, $F_{2,14} = 5.43$, P=0.04). Assessing timing and quantity of within-days macronutrients intakes of pre-competition is crucial for understanding if and how these athletes distribute their nutrition, to support the performance, recovery, and adaptation goals of training. Alongside dietary changes, FP athletes increased total aerobic training duration per day (99 ± 68 to 168 ± 85 $min.day^{-1}$; P=0.02; ES=-0.85, 95% CI= -1.82 to 0.11) from -12 weeks to -4 week pre-competition, and reduced resistance training loads (1555 ± 672 to 377 ± 161 arbitrary units (AU); P<0.01; ES=2.30, 95% CI = 1.11 to 3.49) from -12 weeks to -1 weeks pre-competition. Within the mood sub-scales, vigour was significantly reduced from -12WK (8 ± 3 AU) to -1WK (5 ± 2 AU; 95% CI=0 to 6 AU; P=0.01; ES=1.09, 95% CI = 0.10 to 2.08). These data suggest FP athletes elicit moderate decreases in BM prior to competition via moderate to large adjustments to energy and training practices. Consequently, only vigour was affected in nine FP athletes during pre-competition.

Study 3 (Chapter 5) was a case report assessing the physiological and psychological responses of an experienced FP athlete during the phases of the in-season, representing a late pre-competition phase (Phase 1: -4 weeks before competition), a competition week (Phase 2: -1 week and -2 days before competition) and a recovery phase (Phase 3: +4 and +12 weeks after competition). The athlete experienced a rebound of body mass (+10 kg, +19% from Phase 1) and hyperinsulinemia (>174 $pmol.L^{-1}$) during the 12 weeks of recovery (Phase 3). Potential health consequences associated with relative energy deficiency in sport were also observed, as evidenced by self-reported oligomenorrhea (presented at the start of the study), suppressed RMR_{ratio} (0.90) (the ratio of RMR measured to predictive RMR using the Harris-Benedict equation BM equation), free triiodothyronine (2.6-3.0 $pmol.L^{-1}$) and testosterone concentrations (≤0.3 $nmol.L^{-1}$) when comparing against clinical reference values, and increased mood disturbance (total mood disturbance score = 35-39 AU) in Phase 2. This data showed that after a 12-week overfeeding recovery period following prolonged energy restriction, an experienced international-level FP athlete exhibited rebound hyperphagia. Additionally, some psychological and physiological negative effects observed in the pre-competition phases did not fully recover at 12 weeks post-competition (Phase 3).

Competitive physique sports can place physiological and psychological demands on the athlete (Study 2 and Study 3: Chapter 4 and 5), however, exploratory studies on the lived experiences of FP athletes, especially in relation to health, wellbeing and social life, are scarce. The purpose of this study (Chapter 6) was therefore to shift the lens to a qualitative approach and explore ten FP athletes' personal lived experiences within the sport (during their recovery phase or in the off-season). A two-part semi-structured interview was completed. Using a six-step thematic analysis, the overall theme of this study was a 'dynamic physical, psychological and social rollercoaster experience'. Within this, five key subthemes were identified: Starting the journey, body changes, public success with private isolation, physical and psychological tension and aftercare which manifest themselves uniquely at different stages of the 'rollercoaster experience'. Participants also provided suggestions for the management of health and welfare in physique sports, which included tailored regulations and coach education. Findings offer insights into the complex interplay between the body composition ideal, culture and dieting practices, and how this results in biological, psychological, and social health implications.

Taken together, this thesis provides observational insights into the weight management of FP athletes by assessing both eating and training practices, along with an exploration of the physiological and psychological effects in physique sports. The findings of this thesis serve as a call to action to the bodybuilding and fitness organisations, in enhancing the education packages for athletes themselves and key stakeholders in the sport. Moreover, future research should design, implement and pilot test a multidisciplinary support system in the organisations to identify how FP athletes can be best supported throughout the annual season.

AUTHORS DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Liverpool John Moores University. Apart from the help and advice acknowledged, the work within was solely completed and carried out by the author.

Any views expressed in this thesis are those of the author and in no way represent those of Liverpool John Moores University and the Research Institute for Sport and Exercise Sciences

This thesis has not been presented to any other University for examination either in the United Kingdom or overseas. No portion of the work referred to in this research project has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

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Signed

Nura Alwan

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DEDICATION

I dedicate this work to my mother, Mesalina Salomeea Floares and I dedicate this work to my best friend Nikki Jenkins, in loving memory.

PUBLICATIONS OF WORK WITHIN THIS THESIS

1. Alwan, N., Moss, S, Elliott-Sale, KJ., Davies, I.G., and Enright, K. (2019). A Narrative Review on Female Physique Athletes: The Physiological and Psychological Implications of Weight Management Practices. *International Sports Nutrition and Exercise Metabolism* (Published)
   Doi: https://journals.humankinetics.com/doi/abs/10.1123/ijsnem.2019-0037

2. Alwan, N., Moss, S, Davies, I.G., Elliott-Sale, KJ., and Enright, K. Weight Loss Practices and Eating Behaviours among Female Physique Athletes: Acquiring the Optimal Body Composition for Competition. *PLOS One* (Published)
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PRESENTATIONS OF WORK WITHIN THIS THESIS

1. Alwan N, Davies I, Moss S, McVeigh J, Enright K. 2017. Novel insights into methods practiced among female physique athletes to acquire optimal body compositions. *International Sport & Exercise Nutrition Conference*, 19-21st December. https://journals.humankinetics.com/doi/abs/10.1123/ijsnem.2018-0144

2. Alwan N, Davies I, Moss S, McVeigh J, Enright K. 2017. The effects of manipulative fluid and food intake among GB Female Fitness Athletes during peak week: A proposed protocol**. *Liverpool John Moores University Research Festival.***

MEDIA EXPOSURE OF WORK WITHIN THIS THESIS

- World Bodybuilding Review, Issue 1, p.33. Advertisement to the recruitment for study 1.

1. GENERAL INTRODUCTION

1.1 Introduction

Bodybuilding is a unique sport in which competitors are solely judged on aesthetic appearance rather than performance (Kind and Helms 2023). Yet, it is also frequently seen as a working art and culture (Iraki et al., 2019). In 1946 Benjamin and Joseph Weider established the first organisation specialising solely in bodybuilding events, known as the International Federation of Bodybuilding and Fitness (IFBB) (Vallet, 2017). By the late 1960s the title Mr. Olympia had been created to bring together the world's best male bodybuilders, and became the greatest accolade in the competitive bodybuilding (Andreasson & Johansson, 2014). Since then, the sport has increased in popularity, aided by its acceptance into mainstream media and Western fitness culture (Mosley, 2009). Females were not allowed to compete in physique sports until 1979, and even after being permitted to participate, the sport remained largely male dominated. Since 1994, newer categories (*e.g.*, physique athletes) and divisions (*e.g.*, Bikini fitness and Body fitness) (Liokaftos, 2014) have been introduced into the sport. These newer divisions caused a growth in female participation (Spendlove et al., 2015).

Female physique athletes divide the annual season into two major phases: the in-season (which is further subdivided into a pre-competition phase, competition week, participation in the competition(s), followed by a recovery phase(s)) and an off-season. The in-season typically lasts between 12-24 weeks, whilst the off-season can last months or years with time periods dependent on several contextual factors, including but not limited to, the amount of lean body mass (LBM) and fat mass (FM) the athlete needs to manipulate for division-specific body composition requirements. In competition, FP athletes display their bodies in accordance with these division-specific body composition requirements in front of a panel of judges (See Figure 2.1) (Alwan et al., 2019). For example, Body Fitness emphasises athletic appearance with a small degree of muscularity and separation but no visible striations, while Physique emphasises a heavier bodybuilding-style appearance, although not as 'dry', lean and muscular as Former Women's bodybuilding division and also requires performing a 90-second posing routine. In competition, FP athletes display their bodies in accordance with these division-specific body composition requirements in front of a panel of judges (See Figure 2.1) (Alwan et al., 2019). The complex subjective judging system evaluates components of aesthetic appearance, pre-planned poses (facing front, side on, and showing the back). For some divisions, athletes are required to perform a dynamic fitness routine (Fitness division) or posing routine (Physique division) that are assessed on the parameters of strength, flexibility and routine tempo (Roberts et al., 2020). Because, the key determinant of competitive success in physique sports is a lean and muscular body (Halliday et al., 2016), athletes might be at risk of continuous dieting, weight cycling and adopting (unsafe) acute and prolonged weight management practices like body water and sodium manipulation, excessive exercise volume and/or restrictive eating regimens (Sundgot-Borgen et al., 2013) to acquire and/or maintain such body composition. Ultimately, such behaviours and practices may result in hyponatremia, low energy availability (LEA) leading to consequences of Female Athlete Triad (Triad) and Relative Energy Deficiency in Sports (RED-S) (as described in section 2.12.1) (Mathisen et al., 2019a) and the development of disordered eating (DE) and/or eating disorders (ED) (Mathisen et al., 2019b. Psychological problems associated with EDs include low self-esteem, depression, and anxiety, but can also be fatal (Sundgot-Borgen and Torstveit, 2004).

Throughout the past decade, there has been an increase in research assessing the nutritional and training practices in bodybuilding and physique athletes, however, this has been conducted to a lesser extent in females (Halliday et al., 2016; Mathisen et al., 2019; Trexler et al., 2017) compared to males (Bjørnestad et al., 2014; de Moraes et al., 2019; Fagerberg, 2018; Hackett et al., 2013; Kistler et al., 2014; Lenzi et al., 2019; Pardue et al., 2017; Robinson et al., 2015; Rossow et al., 2013; Schoenfeld et al., 2020).

Weight management and eating behaviours have not been well documented in females, despite the increased participation in FP athletes. Considering the requirements for leanness and muscularity, FP athletes often adopt extreme behaviours (Whitehead et al., 2020) but no study has assessed if experience in the sport is related to extreme behaviours. This is necessary as there may be a danger that novice athletes have insufficient nutritional/training knowledge to safely achieve their aesthetic aims.

It is crucial to understand which body mass (BM) regimen(s) (dietary intakes alongside training practices) an athlete may be following to further understand how they maintain and/or increase LBM and reduce FM and the subsequent impact this may have on both physiological and psychological health. Previous studies have used diet plans from coaches (instead of athletes recording nutritional intakes), omitted information about the data collection period and the assessment tool used, or used a single method of assessing energy intake (EI), which has known limitations. Furthermore, to date, no study has assessed the macronutrient distribution patterns within a pre-competition block. Training practices have only been investigated in male counterparts and it is therefore unknown whether FP athletes perform similar training patterns. Detailed nutritional and training data from FP athletes during a typical pre-competition phase is currently not available, thus making it difficult to prescribe accurate guidelines for athletes to achieve their aesthetic aspirations for competition.

Observational research on FP athletes is limited to a small number of studies on body composition (Halliday et al., 2016; Petrizzo et al., 2017), physiological (Hulmi et al., 2017; Longstrom et al., 2020; Mathisen et al., 2019; Trexler et al., 2017), psychological (Mathisen & Sundgot-Borgen, 2019) and social health (Aspridis et al., 2014; Probert & Leberman, 2009) outcomes. Most of these previous studies have been conducted in one particular division (*i.e.,* Body Fitness division which is also known as Figure division) and as case reports only which may be limited in their generalisability to the wider female physique sport community. A greater knowledge of the demands the sport has on the health status and lived experiences of other divisions across the sporting career is warranted. Such information will provide valuable insights into the specific solutions and systems needed to support the FP athletes' health and welfare across different phases of the competition season.

Moreover, the interest to recognise and appreciate evidence-based dietary and training practices for optimal aesthetic appearance (*i.e.,* favourable manipulate body composition) and health benefits is increasing for many resistance-trained women (Barakat et al., 2020) and other weight-sensitive athletes (Sundgot-Borgen et al., 2013; Robertson and Mountjoy 2018; Reale et al., 2018).

1.2 Aims, objectives and structure of thesis

The primary aim of this thesis was to investigate the weight management behaviours and dietary and training practices used by FP athletes to acquire optimal body composition for competition. A secondary aim was to investigate the physiological, psychological and social health implications of eating behaviours and training practices in FP athletes throughout the annual schedule and to inform practice. To test this aim, four specific objectives were developed:

1) To assess weight loss practices and eating behaviours in FP athletes of different divisions and experience levels in pre-competition (Chapter 3).
2) To assess nutritional and training practices of FP athletes and the subsequent psychological impact during different time-points of the pre-competitive phase (Chapter 4)
3) To determine the physiological and psychological impact of in an international FP athlete competing for a professional status across different phases of the competitive cycle using a longitudinal laboratory study design (Chapter 5)
4) To explore the personal lived experiences and perceptions of the physique athlete's competitive sport career using a qualitative research design (Chapter 6).

[redacted] 2. LITERATURE REVIEW

The published narrative review [Alwan, N., Moss, S.L., Elliott-Sale, K.J., Davies, I.G., and Enright, K. (2019). A narrative review on female physique athletes: The Physiological and Psychological Implications of Weight Management Practices. International Journal of Sport Nutrition and Exercise Metabolism, 29 (6), pp.682-689] sets the scene for understanding the demands and experiences of physique sports in females.

Manuscript has been published in a journal issue: *Accepted author manuscript version reprinted, by permission, from [*International Journal of Sport Nutrition and Exercise Metabolism, *2019, 29 (6): pp.682-689,* https://journals.humankinetics.com/doi/abs/10.1123/ijsnem.2019-0037 © *Human Kinetics, Inc. [or other copyright notice shown in journal, if different]*

The thesis literature review covers other relevant concepts, such as body composition methods, endogenous total body water balance and compartmental distribution, hydration methods, dietary methods and intakes, training regimens, supplementation use, and RED-S framework and recovery in FP athletes. The aims of the literature review were: 1. to define the natural FP athlete; 2. to explore the physiological and psychological implications of the weight management practices experienced by the natural FP athlete; 3. to address future research directions. The general methodologies of body composition, dietary intake and analysis and hydration status for FP athletes' will also be reviewed.

2.1 Background

Physique competitions are events in which competitors are judged on aesthetic appearance rather than on physical performance. Natural (*i.e.*, drug-free) physique competitions have evolved dramatically in recent years, with a growth in organisations, contests and classes (Halliday et al., 2016). The International Federation of Body Building and Fitness (IFBB) hosts over 2,000 competitions annually, in 196 affiliated countries. Approximately 1,300 female and male athletes competed at the World Fitness Championships in 2017 (Rowbottom 2017), and this number is anticipated to increase, with around 1,000 new members joining the sport each year (Parish et al., 2010).

Female physique (FP) athletes have aspirations of achieving a lean and muscular body composition for competitive success (Halliday et al., 2016). Preparing for a natural physique competition provides a myriad of health benefits including improvement in cardiovascular status (Kistler et al., 2014; Robinson et al., 2015), muscle strength (Campbell et al., 2018), rewarding feelings of accomplishment, and transient improvements in self-esteem (Aspridis et al., 2014; Baghurst et al., 2014; Probert et al., 2007). Despite these positive outcomes, numerous unfavorable effects also exist, including, but not limited to: diminished levels of reproductive hormones (Hulmi et al., 2017) and symptoms of DE/ED (Walberg & Johnston, 1991). Available research on FP athletes reveals prolonged periods of sustained energy restriction and intensive training regimens in an attempt to acquire and maintain a lean body composition, indicating an increased risk of LEA and its associated effects (Fagerberg, 2018). For a thorough understanding of the existence, aetiologies and clinical consequences of LEA, readers are directed to reviews by Loucks (2020) and Areta et al., (2021).

Prolonged periods of LEA with or without DE, menstrual dysfunction and low bone mineral density is termed the Female Athlete Triad (Triad), representing a medical condition observed in females who perform high levels of physical activity (Manore, 2015). To describe a wide range of physiological, psychological and performance-related impairments associated with LEA in both sexes, the International Olympic Committee (IOC) introduced the concept of Relative Energy Deficiency in Sport (RED-S) in 2014 (Mountjoy et al., 2014). Considering the health risks of RED-S, and the increasing participation of females in physique events, the purpose of this narrative review was three-fold: 1. to define the natural FP athlete; 2. to explore the physiological and psychological implications of the weight management practices experienced by the natural FP athlete; 3. to address future research directions. The general methodologies of body composition, dietary intake and analysis and hydration status for FP athletes' will also be reviewed.

2.2 Literature Search

A literature search was conducted using databases: PubMed, Web of Science, Google Scholar, and SPORTDiscus (via EBSCO) up to 10th September 2021. Despite slight variation in the terminology used for 'physique athlete' in the literature, synonyms were included in the search strategy. Various combinations of the following search terms were used, for the search: 'physique athlete' OR 'fitness competitor' OR 'bodybuilding' OR 'competitive body-builder' OR 'figure athlete' AND (contest or competition OR dieting OR dietary intake or nutrition OR macronutrient OR micronutrient OR training OR body composition OR peak week

OR practices OR weight loss OR weight regain). Several other search terms associated with health outcomes included: ‘physique athlete’ OR ‘fitness competitor’ OR ‘bodybuilding’ OR ‘competitive body-builder’ OR ‘figure athlete’ AND (energy availability, menstrual cycle OR bone, OR eating OR body image). Any additional articles relevant to the scope of this narrative review were obtained through PubMed via the function “similar articles” or from the reference lists of the included studies.

Criteria for inclusion were: *i*) studies published in English language and in peer-reviewed articles within the past 30 years (*i.e.*, theses or conference abstracts were not eligible), *ii*) studies involving human participants, *iii*) studies with participants who were specifically engaging or been engaged in physique competitions, across any category (*i.e.,* Bikini fitness, Wellness, Women’s Fitness, and Figure), *iv*) studies using female participants, or studies using both female and male participants, and *v*) studies investigating at least one of the following: body composition, nutritional intake, micronutrients, training strategies, psychology, menstrual cycle, hormonal markers, bone mineral density, energy availability, and weight loss/management practices). Exclusion criteria were studies that reported use of performance-enhancing drugs, and only male participants.

2.3 Definition of the natural female physique athlete

Benjamin and Joseph Weider established the first organisation which specialised solely in bodybuilding events, known as the IFBB (Vallet, 2017). To date, the IFBB is one of the most influential amateur sports organisations in the bodybuilding sphere and is an official signatory of the World Anti-Doping Code where athletes participate in random drug testing programs, such as urinalysis and polygraph tests for prohibited substances (IFBB 2014).

Whilst bodybuilding is traditionally a male dominated sport, the growth of female competitors has increased significantly in recent times (Spendlove et al., 2015). This growth in popularity is largely due to the introduction of new female-specific physique categories (*e.g.*, Fitness, Body Fitness and Bikini Fitness) since 1995 (Spendlove et al., 2015; Tajrobehkar, 2016). As these new categories allowed 'smaller' competitors to enter the sport, and reduced the emphasis on muscle mass, they have encouraged healthier practices, indirectly attracting more women from mainstream society than in previous decades (Tajrobehkar, 2016).

Female physique athletes are assessed on aesthetic appearance and posing ability whereby high LBM and low FM are key markers of performance (Kleiner et al., 1994). Competitions involve comparison rounds; wherein athletes are instructed to perform poses, and a final round; in which top ranked athletes perform an individual posing routine (Steele et al., 2018). The intricate scoring system assesses athlete features, such as symmetry, muscularity, size and presentation (*i.e.*, personal confidence, facial beauty, and skin condition) (Choi, 2003; Obel, 1996). Unlike other weight-restricted sports (*e.g.*, male bodybuilding, wrestling and boxing), in which weight categories are utilised, FP athletes are allocated to categories based on their subjective assessment of the amount of LBM and FM, and are then further sub-classified by height (Fry et al., 1991). At one end of the continuum (*i.e.*, bikini fitness), athletes typically have less LBM and higher FM, whilst at the other end (*i.e.*, physique), athletes are diametrically opposed with high LBM and a corresponding low FM (Figure 1). For example, FP athletes who compete in the Bikini and Wellness Fitness divisions place greater emphasis on gluteal and hamstrings muscle mass and segregation, muscle definition (achieved with low FM defined as <16% of body fat percentage) and stage presentation (Helms et al., 2019) and less emphasis on upper-body muscle mass, muscle striations, and vascularity compared to the other divisions (*e.g.,* Body Fitness and Physique divisions).

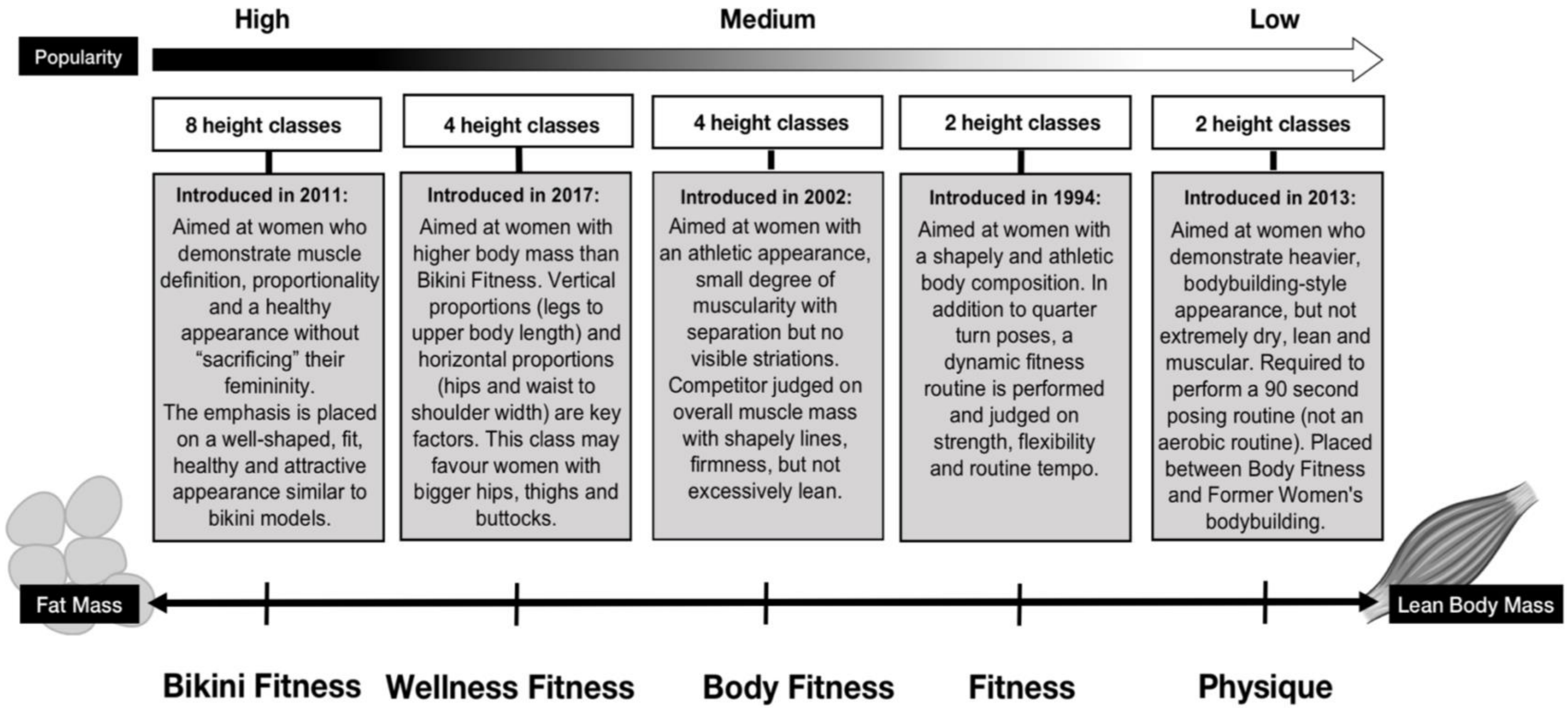

Figure 2.1 *— An overview of the current female categories in women's physique competitions. The categories are progressive steps along a continuum between lean body mass and fat mass. Dry refers to dehydration and the subsequent reduction in body water. The number of height classes in each category is determined by the popularity of the single category. This figure was drawn using information retrieved from the International Federation of Bodybuilding and Fitness website (Source: Alwan et al., 2019 reused with permission).*

2.4 Body composition methods in FP athletes

Body mass can be separated into different and relative compartments (based on each compartment's composition of different tissues), including FM, FFM and bone mineral content (Holmes and Racette 2021). Methods to assess body composition vary in their accuracy, reliability, and practicality, with selection influenced by factors like cost, safety, invasiveness and expertise required (Kasper et al., 2021). What is clear from the literature, is that the methods examining body composition in FP athletes are diverse.

FP athlete body composition studies have used either the bioelectric impedance analysis (BIA) method (doubly indirect but multi-compartmental assessment tool) (De Souza et al., 2018; Gentil et al., 2017) or Dual-energy X-ray absorptiometry (DXA) scan technology (a three-compartmental indirect method) (Mathisen et al., 2019; Petrizzo et al., 2017) or both (Graybeal et al., 2020; Tinsley et al., 2019; Van der Ploeg 2001). Others have used the skinfold thickness method (a two-compartmental doubly indirect method) and combined this with DXA (Hulmi et al., 2016: Mursu et al., 2023; Halliday et al., 2016) or BIA (Longstrom et al., 2020; Trexler et al., 2017), while one study has allowed participants self-report body composition (Chappell et al., 2018).

A multi-compartment measure such as DXA is widely used as the principle method in athletic populations, considering its ability to assess both whole body and different regionalised bone mineral content/density alongside LM and FM (Reilly et al., 2009). Seven studies analysed body composition of FP athletes using DXA (Hulmi et al., 2016; Mathisen et al., 2019; Petrizzo et al., 2017; Tinsley 2019;

Halliday et al., 2016: Mursu et al., 2023 and Van der Ploeg et al., 2001), however three of these studies did not report or based their coefficient variation data of DXA on other literature rather than testing their own reliability (Nana et al., 2015). The reliability of DXA may also be reduced without standardised hydration (Barreira and Tseh 2020) or nutrition (Bone et al., 2017) prior to assessment. Given that FP athletes' use of carbohydrate and water manipulation (Chapter 4, Study 1) and creatine supplementation during pre-competition (Chappell et al., 2018) the results of these studies should be interpreted with caution.

As another multi-compartmental but a doubly indirect assessment tool, BIA measurement is grounded on the principle that electrical current passes at varying rates throughout the body and as such, can establish the composition of differing tissues based on their conductivity (Dehghan & Merchant, 2008). Five studies utilised BIA for body composition assessment (De Souza et al., 2018; Gentil et al., 2017; Longstrom et al., 2020; Tinsley et al., 2019 and Trexler et al., 2017). Like DXA, the reliability of BIA might be affected when nutrition (Slinde & Rossander-Hulthen, 2001), hydration (Lukaski et al., 1986), exercise (Caton et al., 1988) statuses and body temperature (Gudivaka et al., 1996) are not standardised prior to assessment. None of the mentioned FP athlete BIA studies addressed these factors in their methodologies (other than Tinsley et al., 2019).

Skinfold thickness measurements involve applying callipers to a double fold of gripped skin (Martin et al., 1985) using a two-compartmental indirect (*i.e.*, measured in the sum of skinfolds) and doubly indirect (if a percentage of FM is calculated) method. All the above-mentioned studies performing the skinfold thickness method used different available prediction equations to estimate body fat percentage, thus making comparisons between studies difficult. However, given the inaccuracies manifested in FM measurement produced from predictive skinfold thickness equations, focusing solely on the sum of skinfold thickness (often 8 sites) is recommended as a more reliable and sensitive indicator of body compositional change over time (Reilly et al., 1996; Johnson 1982). Future research utilising the skinfold thickness method should consider this approach. In Chapter 5 (study 3) the sum of 8 sites and individual sites of skinfold thickness were presented of a single FP athlete in pre-competition, competition week and recovery phases.

Despite these body composition methods, it should be noted that physique athletes are not objectively judged on body composition measures in competition. Instead, athletes are judged and compared with each other, using judges' subjective assessment of FM and LBM, symmetry, leanness, posing and other factors (as defined in Figure 2.1).

2.5 Body composition in competition

Typically, an annual schedule for the physique athlete is divided into an off-season phase and a pre-competition phase (Hackett et al., 2013). Within the off-season phase, physique athletes manipulate resistance training variables including volume, intensity and frequency for the purpose of gaining LBM (Spendlove et al., 2015). This period can last years and is characterised by a positive energy balance, in conjunction with a high protein intake to stimulate muscle anabolism (Campbell et al., 2018; Phillips, 2004). In the pre-competition phase, the majority of athletes attempt to reduce FM and preserve LBM using a combination of rigorous resistance and aerobic training, while manipulating their nutritional intake to achieve a negative energy balance (Hackett et al., 2013; Petrizzo et al., 2017). The pre-competition phase lasts between 12 and 24 weeks (Mitchell et al., 2018) and athletes are likely to compete between two to three times per year (Chappell et al., 2018). Usually, the pre-competition phase is followed by a recovery phase (a transition to off-season), during which athletes increase total energy intake (TEI) and decrease total training load (Hulmi et al., 2017). Previous research reports the magnitude of weight loss is in the range of 6-10 kg over a 12-24 week period (Table 2.1). This suggests that FP athletes pursue a gradual approach to weight loss (~ 0.4 kg per week), similar to male bodybuilding and physique athletes (~ 0.6-0.8 kg per week) (Chappell et al., 2018; Kistler et al., 2014; Robinson et al., 2015; Rossow et al., 2013). In the end stages of the pre-competition phase, FP athletes achieve 8.6 - 17% body fat (Hulmi et al., 2017; Rohrig et al., 2017; Tinsley et al., 2019a; Trexler et al., 2017), which is exceptionally lower than the recommended values for female athletes (Sundgot-Borgen & Garthe, 2011). For the first time, Chapter 3 (Study 1) assessed the weight loss history in a large cohort of FP athletes (from different experience levels and divisions) and the frequency of practices used to acquire weight loss for competition.

Table 2.1: *Overview of the recent studies of reproductive health of female physique athletes (Source: Alwan et al., 2019)*

Study	N	Body weight change ('from and to' Body fat %)		Time period (weeks)	TEST		E_2		T_3		T_4		CORT		Ghrelin		LP		TSH		IN		Method for menstrual status	Absence of menstruation	Bone mass density (DXA)
		CP	**RC**		**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**	**CP**	**RC**			
Halliday et al. 2016	1 F	-8.3kg; (15.1-8.6%)	+5.2kg; (8.6-14.8%)	20 CP; 20 RC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Self-report	9 weeks pre- and up to 71 weeks post-competition	NA
Hulmi et al. 2016	27 F	-7.8kg (23.1-12.7%)	+6.1kg (12.7-20.1%)	20 CP; 17.5 RC	↓	(↑)	↓	↑	↓	(↑)	↓	↑	-	-	-	-	↓	↑	↓	↑	-	-	Serum and self-report	11.5% pre-competition and 28% post-competition	↓CP; ↑RC
Mathisen et al., 2020	25 F	-3.8 kg (25-17%)	(17-21%)	Not reported	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Self-report	8% at baseline, 24% pre-competition	Spine Z-score ↓CP for five of the participants but overall no change
Trexler al. 2017	8 F 7 M	-	+3.9kg (12.5-14.9%)	4-6 RC	-	↑		-		-		-		↑↓		↑		↓	-	-	-	↑	Saliva	-	-
Petrizzo et al. 2017	1 F	-7.7kg (24.4-11.3%)	-	24 CP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Self-report	Oligomenorrhea	No change
Rohrig et al. 2017	1 F	-10.1kg (30.5-15.9%)	-	24 CP	↑↓	-	↑↓	-	-	-	-	-	↑↓	-	-	-	↓	-	↓	-	-	-	Serum and self-report	8 weeks pre-competition	-
Tinsley et al., 2018	1 F	-6 kg (20.3-11.6%)	+6.8kg (11.6-18.8%)	18 CP(1) 7 CP (2) 9 RC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Self-report	12 weeks pre-competition (1) and up to 12 weeks post-competition (2)	NA

F indicates female physique athletes, M indicates male physique athletes, ↑↓ indicates fluctuation, CP indicates the pre-competition phase, RC indicates recovery phase, ( ) indicates not recovered to initial baseline values, (1) indicates 1st competition and (2) indicates a 2nd competition. TEST = Testosterone, E2 = Estradiol, T_3 = Triiodothyronine, T_4 = Thyroxine, CORT = Cortisol; TSH= Thyroid stimulating hormone; LP= Leptin, IN = Insulin; DXA = Dual-energy X-ray absorptiometry. NA = Information not available

2.6 Dietary methods and analysis

2.6.1 Methods to measure dietary intake

It is important to quantify dietary intake, though this can be an extremely complex and challenging task within human science (Burke et al., 2018; Capling et al., 2017) when trying to obtain valid and reliable information about athletes habitual dietary intake. Self-report assessment of dietary intakes in athletic populations are typically poor, owing to respondents losing the motivation and attention to scribe/write down dietary intake, particularly over longer recording periods (Ortega et al., 2015). A recent systematic review (Capling et al., 2017b) found that in athletic populations self-reported TEI was under-reported by ~19% (range 0.4-36%) which represents approximately 600 kcal, when compared to total energy expenditure (TEE) (assessed by doubly labelled water (DLW)) and changes in BM. This may be explained by errors of omissions and under-reporting portion sizes of perceived 'unhealthy' foods and over-reporting of perceived 'healthy' or 'nutritious' foods (Burke et al., 2018). Taken together, this raises a concern over the accuracy of the dietary data in many studies in physique sports due to the lack of careful consideration to dietary data collection and analysis.

Given that most dietary intake assessments are self-reported in free-living conditions, the cooperation, feasibility and burden posed on the individual needs to be considered when choosing the most suitable dietary method. In addition, the researcher must also consider the dietary data analysis. Previous analysis of dietary intakes has led to poor validity and inter-practitioner reliability (~16%), even when dietary analysis was performed by experienced and certified sport nutritionists (Sport and Exercise Nutrition Registered) using a standalone methodology (Stables et al., 2021). Various techniques can be used in an attempt to improve the accuracy of dietary data collection and analysis (by cross-referencing with other assessment techniques), representation of habitual dietary intake (by measuring more time-points) and inter-practitioner variability (more than one practitioner analysing the data) (Burke et al., 2018). Whilst there is currently no gold standard method for assessing dietary intake, there are multiple commonly used methods, each with their own advantages and disadvantages (Burke, 2015; Capling et al., 2017). An overview of dietary assessment methods is provided in Table 2.2.

Table 2.2: *Dietary assessment methods: Overview, duration of data collection, advantages, disadvantages and applications in clinical research and practice adapted from Burke (2015).*

Dietary intake method	**Overview of method**	**Duration of data collection**	**Advantages**	**Disadvantages**	**Applications**
			Retrospective		
24-hour recall	Participant describes foods consumed over the last 24-hour period or a typical day	24-hour	Speedy to implement Low burden for the subject Interview can be structured around daily activities Does not alter dietary intake Suited to epidemiological research	Relies on participants honesty, memory and food knowledge Requires trained interviewer. Day for recall may be "atypical" Suitable for group surveys, but not representative of individuals normal habitual intake	Mainly used to rank food or nutrient intakes of groups of people. May not be suitable for individual assessment
Food Frequency Questionnaire (FFQ)	Participants asked how often they eat foods from a standardised list and to estimate portion sizes often using photos of food models as a prompt	From 24-hour period to open-ended	Can be self-administered to lower burden on the investigator Can be used to cross-check data obtained from other methods Validated for ranking individuals Can be modified to target certain nutrients Can be automated to allow quick processing by researcher	Relies on participants honesty, memory literacy and food knowledge Validity dependent on the food list and the quantification method	Mainly used to detect, measure or rank specified nutrients or food intake in groups or individuals. Used for cross-checking data obtained from other methods

Diet History	Open-ended interview concerning food use, food preparation, portion sizes, food like/dislikes and food checklist	Open-ended or over a specific period	Accounts for daily variation in food intake by investigating a "typical" day Can target contrasts between periods of interest as a sub-theme Collects information on timing of intake and factors that influence food patterns	Relies on participants honesty, memory, food knowledge Labour intensive and time consuming Requires trained interviewer Mostly appropriate for qualitative assessment rather than quantitative	Mainly used to assess usual intake of individuals in clinical practice. Good for longitudinal studies.
Written food diary (diet record)	Weighed	May be undertaken for 1-7 days	Provides a more accurate quantification of foods than household measures. As recording duration increases, the ability to track usual intake increases. Considered the "gold standard for dietary assessment"	Relies on participants' honest and food knowledge. Time consuming for participants to keep and researcher to process. Extended recording duration can reduce compliance. Distorts food choice and quantity: Participants alters their diet to improve their intake or to reduce the workload of recording	Mainly used to determine eating habits for 1-7 days. Used for validating other methods
	Household measures (descriptions of cups, teaspoons, dimensions of food portions etc.)		Improved compliance with subjects compared with weighed record Less alteration of normal eating pattern compared to weighted or semi-weighed records	See comments for weighed record. Requires checking by trained individual. Needs standardised set of household measures Subjective/inaccurate assessment of portion sizes.	Mainly used for invested athletes who have access to correct serving utensils
Remote food photography method	Food plate is photographed pre- and post- consumption with a smartphone in real time. Energy and nutrient intake are estimated by comparing the food images to images of foods with a known portion size.	Instant, real time and open-ended	Can be used to cross-check data obtained from methods abovementioned Self-administered Fast process to implement Low burden for the subject	Relies on participants honesty May distort food choice and quantity. Athletes may alter their habitual intakes Subjective/inaccurate assessment of portions size from images Subjective/inaccurate assessment of ingredients in multi-ingredient dishes (e.g., curry), if no additional details are provided to the assessor.	Requires high level of specialist and specific training prior to use in order to yield reliable data When used alone, validity and inter-practitioner reliability was reported as poor (Stables et al., 2021)

2.6.2 Food records (diet history) and weighted food inventory

Food records are the most used method to assess dietary intake in applied sport and exercise nutrition research and practice (Burke, 2015) and are frequently used with physique athletes (Lenzi et al., 2019; Longstrom et al., 2020; Mathisen et al., 2019; Trexler et al., 2017). This method requires individuals to record (normally by writing down or via input into a digital application) foods and beverages consumed over a specified time-period (*i.e.,* 3-7 days) and include information about the timing, quantity, brand (if appropriate), preparation of intake, cooking method (if appropriate) and amount of food or drink left-over (if appropriate). Ideally, this information is recorded at the time of consumption to avoid reliance on participants memory at a later time point (Ortega et al., 2015).

A more accurate measure of dietary intake compared to standalone food records is the weighed food inventory (Burke, 2015). This is also a common method in physique studies (Chappell et al., 2019; Halliday et al., 2016; Mitchell et al., 2018) which involves precise weighing (using a portable weighing scale) and recording of foods and fluids before consumption. This process is then repeated after the consumption of each meal and drink to measure and food or fluid which has not been consumed. Consequently, errors in portion size estimation is reduced (Thompson et al., 2010). Weighing food and fluid items of each meal, however, places an increased time and effort burden on the athletes. This can result in athletes failing to report consumed foods and fluids (*i.e.*, under-reporting) or altering dietary intake and habits (Larson-Meyer et al., 2018). Considering this, weighing individual food and fluid items at the time of consumption may not be convenient for athletes with busy lifestyles, training schedules and irregular eating windows.

Additionally, this process requires athletes to have quick access to scales to allow dietary items to be physically weighed, which is difficult when travelling (Larson-Meyer et al., 2018). Although extensions in the recording period increases the reliability of collected dietary data this places a greater burden on the participant and may reduce compliance and alteration (Garthe et al., 2013). To this end, it would require well-motivated individuals to weigh every food item from each meal over a specified data collection period.

Unique to physique sports, physique athletes and bodybuilders (Helms et al., 2019; Mitchell et al., 2017) habitually and carefully weigh dietary intake at each meal time (to the nearest gram) and/or target a specific quantity of macronutrients to consume daily with minimal deviation in the pre-competition phase (Halliday et al., 2016; Helms et al., 2019; Mitchell et al., 2017). It is therefore not uncommon for physique sports athletes to routinely prepare weighed meals in plastic food containers and transport the prepared food containers with them to work, training and when travelling to allow consumption of the correct weighed meals. Weighing foods and fluids occurs less frequent in the recovery and off-season (Chaba et al., 2019).

2.6.3 24-hour recall

A 24-hour recall is a retrospective method to estimate dietary intake during which the individual (being assessed) provides information on the food and fluid intake from the preceding day (Burke, 2015). The recall is typically performed as an informal or formal interview (between the researcher and the individual being assessed) face-to-face or by telephone or video call. The benefits of using this method include being performed quickly and it can be fitted around the athlete's schedule (Larson-Meyer et al., 2018). If conducted alongside other methods, the interviewer can revisit the dietary records and check for completeness and clarify any additional information, increasing the accuracy of the dietary intake data. However, this process requires a skilled 'interviewer' (Nightingale et al., 2016). This method also requires honest and accurate memory recall (Larson-Meyer et al., 2018) to establish true eating patterns, otherwise it may not represent an athlete's habitual dietary intake and true habits. Given that many physique athletes consume monotonous and rigid dietary patterns in accordance with the pre-competition period (Halliday et al., 2016; Helms et al., 2014) this is a useful method in physique sport studies (Chappell et al., 2019; Vega & Jackson, 1996), which should be used in conjunction with another prospective method to obtain representative dietary data.

2.6.4 Dietary analysis

After completion of the chosen dietary assessment method, the next stage is to analyse the participants dietary intake for specific food types, EI, macronutrient composition and meal timing. This is conducted using food composition data bases, which provide information on the average composition of food and fluid items. It should be highlighted that even the most experienced researchers/practitioners can input coding errors into databases (Braakhuis et al., 2003), specifically for the remote food photography method (Stables et al., 2021). Errors can arise due to the need to match to the closest item in the data base when the specific foods are not listed, as well as errors may also exist in the food composition values on the data bases (Braakhuis et al., 2003; Larson-Meyer et al., 2018). Moreover, errors include systematic bias of food types that are missing from the databases for example sports foods or supplements that many athletes consume regularly, misreading of the food item and therefore possibly error in data entry, and the difficulty in analysing some meals with multiple ingredients (*e.g.*, a chicken curry with mixed vegetables sauce and white rice). Such errors have shown high variability in estimates of nutrients from athletes over a 7-day period (Braakhuis et al., 2003). One of the widely used nutrition software by sport nutritionists in the UK is Nutritics (Nutritics, Dublin, Ltd, Ireland). Nutritics has been used in physique sport studies (Chappell et al., 2019; Robinson et al., 2015), while others have used other country-specific analytics software's including Norwegian Food Composition Table, Diett.no (Mathisen et al., 2019) and United States National Nutrient Database, United Stated Department of Agriculture (Halliday et al., 2016). Such softwares allow manual addition of new food, recipe meals and sport supplement, however when manual entries are not possible, researchers/practitioners may choose to input food items with a similar nutritional characteristic. This practice may increase inter-practitioner variability and overall error of estimating nutritional content of dietary assessments. Therefore, it is important that researchers are trained in such specialist computerised softwares to make recommendations based on the dietary analysis, otherwise professional interpretation may result in further errors.

2.7 Dietary intakes and supplement use across competition cycle among FP athletes

2.7.1 <u>Dietary intakes</u>

Overall nutritional intake, in particular patterns of timing, type and total amount of food and fluid from FP athletes are likely to shift according to the phase of the competitive season (*i.e.*, pre-competition including competition week, recovery and off-season). In the pre-competition phase, diets are characterised as restrictive with often limited food variability (Kleiner et al., 1994). In particular, total energy and macronutrient targets are followed strictly throughout the year by weighing food items and meals, to ensure total energy and macronutrient quantities are met each day (Helms et al., 2019). However, during the off-season, nutritional intakes are less structured and monitored allowing for FP athletes to consume diets which can be described to be less restrictive (Iraki et al., 2019).

A systematic review (Spendlove et al., 2015) identified 18 articles on dietary intake across male and female bodybuilders. The results from eight studies on female bodybuilders show TEI varying across the competitive season which higher TEI during the post-competition phase (13,600 ± 244 $kJ.day^{-1}$) and lower in the weeks prior to competition (*i.e.,* pre-competition phase) (5081± 1697 $kJ.day^{-1}$). In addition, FP athletes show a lower CHO intake during pre-competition (2.9-3.6 $g.kg^{-1}.day^{-1}$) compared to the recovery phase (7.5 $g.kg^{-1}.day^{-1}$) which is driven by the requirement and the need to reduce FM in preparation for competition success. In contrast, Spendlove et al., (2015) shows protein intake to be lower or similar during pre-competition compared to the recovery phase (pre-competition: 0.8-2.8 $.kg^{-1}.day^{-1}$ *vs.* recovery: 2.2 $g.kg^{-1}.day^{-1}$). Although the dietary intake of female bodybuilders has been well described (Spendlove et al., 2015) the majority of the available evidence is dated (1980-1990), and have not been researched using FP athletes. As such, the current literature may not represent habitual dietary intakes and behaviours in FP athletes where body composition requirements during training and competitions are different.

Since the Spendlove et al., (2015) systematic review, there have been a number of studies, that have examined dietary intake in FP athletes (Halliday et al., 2016; Hulmi et al., 2016; Mathisen et al., 2019; Tinsley et al., 2019; Trexler et al., 2017). See Table 2.3 for dietary assessment methods and outcomes in studies on FP athletes during different competitive phases.

Although previous assessments of nutrition strategies exist, the literature has utilised diet plans derived from coaches to analyse dietary assessments in FP athletes (Mathisen et al., 2019; Tinsley et al., 2019b). Providing diet plans designed by coaches, cannot be considered a measure of an individual's habitual EI but more the ability of the individual to follow a set dietary plan. Additionally, all previous research has used single methods of assessing EI (Halliday et al., 2016; Mathisen et al., 2019; Tinsley et al., 2019; Trexler et al., 2017) using 1-7 days food written diaries, which has known limitations of underreporting when conducted in isolation without a second or third method of dietary assessment. Finally, Hulmi et al., (2016) did not report the method used for dietary tracking with 50% of participants did not report their intakes. Therefore, there is a definite need to assess and analyse pre-competition nutrition practices using multiple dietary methods to increase validity and reliability. This was therefore analysed in Chapter 4 (Study 2) in FP athletes using two different methods (3-day food diary combined with 24-hour recalls). Finally, addressing the daily distribution of both CHO and protein patterns (*i.e.*, timing and type) in relation to daily training, will provide a greater level of evidence; that to date, does not exist with FP athletes.

Table 2.3: *Dietary assessment methods and outcomes across different phases of the competitive cycle in observational studies of FP athletes (studies published between 2016-2019)*

Reference	N	Dietary method	Time-point when nutritional data was collected	Energy intake (Kcal.day)	Energy intake (Kcal. kg^{-1}.day)	Carbohydrate Intake ($g \cdot kg^{-1} \cdot day^{-1}$)	Protein Intake ($g \cdot kg^{-1} \cdot day^{-1}$)	Fat Intake ($g \cdot kg^{-1} \cdot day^{-1}$ (or % of total EI))
Halliday et al., (2016)	1 F	7-day (Weighed) food written food diary	Baseline CP: 20 weeks pre-competition RC: 20 weeks post-competition#	B: 2010.0 CP: 1798.0 – 1541.0 RC: 2023.0 – 2032.0#	B: N/A CP: 36.6 - 30.9 RC: 36.7 - 36.9	B: 4.1 CP: 2.7 - 3.8 RC: 4.2#	B: 2.2 CP: 2.7 - 3.0 RC: 2.4 - 2.8#	B: 48% CP: 24-40% RC: 34-49%#
Hulmi et al., 2016	27 F	Method N/A 50% of participants did not report	Baseline CP: 10 weeks pre-competition RC: 14-19 weeks post competition	B: 2367.0 ± 427.0 CP: 1798.0 ± 372.0 RC: 2216.0 ± 523.0^	B: 37.0 ± 6.6 CP: 31.4 ± 5.8 RC: 38.0 ± 9.9^	B: 3.4 ± 1.0 CP: 2.1 ± 0.8 RC: 3.2 ± 1.3^	B: 3.2±0.6 CP: 3.1±0.6 RC: 3.3± 0.8^	Ba: 1.0 ± 0.3 CP: 1.0 ± 0.3 RC: 1.0 ± 0.2^
Trexler et al., (2017)	8 F 7 M	1-3-day food written diary	CP1: 7 days before the competition CP2: 1 day pre-competition RC: 4-6 weeks post-competition	CP1: 1980.0 ± 726.0 CP2: 3761.0 ± 1827.0 RC: 2545.0 ± 684.0	N/A	CP1: 3.1 ± 1.9 CP2: 6.2 ± 3.4 RC: 3.9 ±1.0	CP1: 2.8 ± 0.8 CP2: 2.6 ± 1.2 RC: 2.5 ± 0.7	CP1: 0.8 ± 0.4 CP2: 2.2 ± 1.1 RC: 1.2 ± 0.6
Tinsley et al., (2019)	1 F	No real-time recording (diet plans provided by coach)	CP1: 18 weeks before 1st competition CP2: 7 weeks between 1st and 2nd competition	CP1: 1610.0 TD (1500.0 non-TD) CP2: 965.0**	CP1: 24.8 TD (23.1 non-TD) CP2: 16.1**	CP1: 2.5 TD (1.7 non-TD) CP2: 0.33**	CP1: 2.6 TD (2.7 non-TD) CP2: 2.8 **	CP: 0.5 TD (0.6 non-TD) CP2: 0.4**

Mathisen et al., (2019)	25 F	4-day (Weighed) food written food diary)
		4 athletes provided diet plans instead
			Baseline
			CP: 2 weeks pre-competition
			RC: 4 weeks post-competition
				B: 1783.0 (1565.0-2000.0)
				CP: 1502.0 (1270.0 - 1733.0)
				RC: 2018.0 (1774.0 – 2263.0)
					B: 40.0 (35 - 45)//
					CP: 33.0 (28 - 38)//
					RC: 43.0 (37 - 49)//
						B: 2.6 (2.0 - 3.2)
						CP: 2.0 (1.4 - 2.7)
						RC: 3.1 (2.4 - 3.7)
							B: 2.6 (2.3 - 2.9)
							CP: 3.0 (2.7 - 3.3)
							RC: 2.5 (2.1 - 2.8)
								B: 25.5 (21.1-29.9)
								CP: 20.1 (15.4-24.9)
								RC: 28.3 (23.2-33.3)

F indicates female physique athletes, M indicates male physique athletes, CP indicates the pre-competition phase, RC indicates the recovery phase. ^ 27 FP athletes, however, only 18 provided nutritional data in the recovery phase, N/A denotes the study did not report. B indicates baseline data (B has not been reported in every study), # indicates weighed food written diary and food diary estimates were used as the dietary method.

Macronutrients reported as $g.kg^{-1}.day^{-1}$ if not otherwise stated. EI denotes energy intake, // indicates the study reported kcal· kg LBM^{-1}·day. (Brackets) denotes a 99% confidence interval reported by Mathisen et al., (2019) study only. TD denotes training day, ** indicates no different dietary intake between training day and non-training day.

2.7.2 Dietary supplements

Dietary supplements is a major component for the dietary strategies among physique athletes (Tinsley et al., 2019a). In particular supplements are consumed to maintain or increase LBM, enhance fat loss and prevent micronutrient deficiencies (Spendlove et al., 2015). Based on this systematic review (Spendlove et al., 2015), four studies which met the inclusion criteria, reported protein powders, amino acids, vitamins, minerals and L-carnitine to be the most frequent and common supplements used. However, it is worth noting that this systematic review was conducted in women's bodybuilding (prior to physique divisions existence in organisations) and so does not necessarily reflect what supplements FP athletes use. More recently Chappell (Chappell et al., 2018), reported (using a self-report survey) that 16 UK-based FP athletes consumed a daily average of five supplements to complement dietary intakes over the course of the pre-competition phase. Protein powder (89%), multivitamin (60%), Branch Chain Amino Acids (BCAA) (54%), creatine supplement (51%), Omega 3 (47%) and fat burners (containing caffeine) (37%) were the most commonly used supplements use in FP athletes (Chappell et al., 2018). In agreement with Chappell et al., (2018), case reports with single participants have commonly detailed the use of whey protein powder and creatine monohydrate (in early pre-competition block) (Halliday et al., 2016; Petrizzo et al., 2017). Additionally, BCAA are typically consumed before or after aerobic sessions (Petrizzo et al., 2017; Tinsley et al., 2019a) in an attempt to maximise training adaptation and protein synthesis (Jackman et al., 2017). At present, it is currently unknown whether these supplements are used in other phases of the competition season (*e.g.*, recovery phase). Many studies also fail to provide qualitative details of what type of supplements were used and specify when they were used (Hulmi et al., 2017; Mathisen et al., 2019). Although dietary supplements pose less of a threat to the health of a physique athlete compared to image and performance enhancing drugs (IPEDS) (Spendlove et al., 2015), assessment of FP athlete knowledge on supplement ingredients, benefits, consequences and contamination risk is also currently lacking. Investigating this could reveal if athletes are at health and doping violation risks based on poor education about the supplement they are taking. For example, it would be prudent to investigate whether their supplements are tested for banned substances according to the UKAD and WADA codes.

2.8 Training regimens of physique athletes

Athletes have known for over 40 years that resistance training is an effective method of training to induce skeletal muscle hypertrophy via enlargement of individual muscle fibres (Goldberg et al., 1975). Considering this, it has been shown that aspiring FP athletes engaging in 8-weeks of supervised periodised resistance training showed a 2.1 kg increase in FFM (Campbell et al., 2018) when combined with a high protein intake (2.5 $g.kg^{-1}.day^{-1}$). Training load can be classified as either external training load, which is the amount of exercise completed by the athlete, independent of the characteristics (*i.e.*, heart rate (HR) or rating of perceived exertion). Internal training load solely considers the internal characteristics of the athlete and how the athlete responded to the training session (Campbell et al., 2017). Quantifying the training load from resistance training is somewhat difficult. Internal training load can be assessed using session rating of perceived exertion (sRPE), HR, training impulse, blood lactate concentrations, HR variability and HR recovery, while external training load may include weight lifted, training volume, power output, and neuromuscular functioning (Campbell et al., 2017).

Research on training regimens in FP athletes remains scarce. The majority of studies have not reported exercise data (Haliday et al., 2016; Petrizzo et al., 2017; Rohrig et al., 2017; Mathisen et al., 2019). One case study showed an FP athlete typically trained over 4-6 days split routine, with a specific muscle group targeted 1-2 times a week (Tinsley et al., 2019a). Such training programmes generally include 25-35 working sets per workout, with 10-20 sets per muscle group and target repetitions varying from 4-20 repetitions per set. During the 8-month assessment period, the athlete completed 10 different programmes, so each programme lasted on average 3.3 weeks (ranging between 1.7 – 5.3 weeks). Complete details of the programme were not disclosed based on the request of the coach, as such the representation of the exercise program was somewhat ambiguous.

Nonetheless, to aid fat loss whilst maintaining LBM, athletes may engage in high-intensity interval training and steady-state aerobic exercise during pre-competition (Escalante et al., 2021). For example, the case study athlete (Tinsley et al., 2019) engaged in aerobic training 3-6 times a week of 30-50 min, in duration with a target HR of 115-150 beats per minute either via cycling, walking/running/stairs and/or stepping exercises. Another case study (Petrizzo et al., 2017) reported four times a week of 30-40 min in duration of high-intensity interval training in the ten weeks prior to competition. There are many ways in which physique athletes perform aerobic exercise (*i.e.*, different types, intensity, duration and frequency) based on preference, individual recovery rates, schedules, BM goals and injuries (Helms et al., 2015). Thus, studies show varied aerobic strategies.

In addition to the training practices, posing practice also appears to be implemented into FP athlete regimens during the pre-competition phase (Robinson et al., 2015). Posing practice involves repeatedly holding no-load isometric muscle contractions of the large muscle groups for 30-60 seconds (Maeo et al., 2013; Schoenfeld et al., 2020). As quoted in Schoenfeld et al., (2020) by Arnold Schwarzenegger: "*A basic physique is developed by training, but posing adds sharpness and quality*" (Schwarzenegger and Dobbins, 1998) and therefore also a crucial part of athletes training. At present, it is yet to be determined whether FP athletes follow a similar training pattern to male bodybuilders. Furthermore, no studies have yet quantified resistance training volume or load of FP athletes and how this is periodised during the pre-competition phase. This was therefore assessed in Chapter 4 (Study 2). Irrespective of how and what training FP athletes perform, it is evident that the overall training demands of FP athletes lead to mood changes (Newton et al., 1993; Rohrig et al., 2017). For example, sensations of increased fatigue, depression, tension, confusion and reduced vigour across time are often reported (Newton et al., 1993), compared to healthy females (Hulmi et al., 2017). However, a limited amount of studies (Hulmi et al., 2017; Newton et al., 1993; Rohrig et al., 2017) have measured mood changes during the pre-competition period, with two of them being case reports involving single participants. More research is warranted to assess mood changes across different phases of the competitive cycle to understand the psychological impact of weight loss.

2.9 Strategies to manipulate body composition during competition week

Whilst female physique athletes employ a gradual approach to fat loss, acute weight loss practices occur during the competition week (Helms et al., 2014). Peer-reviewed articles suggest fluid, salt, and CHO manipulation is commonly practised to reduce body water content in order to enhance muscle definition on competition day (Mitchell et al., 2017; Shephard, 1994). More than one-third of twenty-two FP athletes practised water manipulations (36%), whereas about three-quarters practised CHO manipulations (77%) (Chappell & Simper, 2018). Water loading, followed by water restriction is allegedly used to modify renal hormones and encourage urination beyond the period of increased fluid intake, resulting in reduced body water (Helms et al., 2014; Mitchell et al., 2017). The physiological effects of water loading have only been investigated in male combat sport athletes with a purpose of making-weight (Crighton et al., 2016; Reale et al., 2018), as opposed to physique athletes trying to enhance their aesthetic appearance. The acute weight loss experienced early in the competition week (~7-5 days prior to competition) is likely to be mediated by glycogen depletion prior to a CHO loading protocol (Olssen and Saltin, 1970). Female physique athletes reduce their CHO intake from 4.1- 4.5 $g.kg^{-1}.day^{-1}$before entering the pre-competition phase, to 1.2 - 2.7 $g.kg^{-1}\cdot.ay^{-1}$at the end stages of pre-competition phase (Halliday et al., 2016; Rohrig et al., 2017). In one case, daily CHO intake was reduced to ~ 0.3 $g.kg^{-1}.day^{-1}$, three days prior to competition (Tinsley et al., 2019a). From the available evidence, it appears that during the pre-competition phase, FP athletes fall considerably below the CHO recommendations for moderate volume training (5-7 $g.kg^{-1}\cdot day^{-1}$) (Manore, 2002). Addressing the distribution of CHO intake throughout the day and in relation to training, could provide further insights into the strategies used to optimise body composition (Slater & Phillips, 2011). Based on limited data, the efficacy and safety of competition week strategies in physique events are still unknown but might be detrimental to athlete health (Chappell & Simper, 2018; Helms et al., 2014) by increasing the risks associated with hyponatremia and glycogen depletion (Slater & Phillips, 2011).

Bodybuilding and physique athletes also adopt CHO loading protocol (after the CHO depletion phase) as a performance-enhancing strategy prior to competition. This strategy is used in the belief that greater glycogen stores can increase muscle size allowing athletes appear more muscular during competition (Balon et al., 1992; de Moraes et al., 2019). CHO loading, a dietary strategy introduced in 1960's, increases muscle glycogen stores above normal resting values allowing exercise to be prolonged by delaying the onset of fatigue (Bergström et al., 1967; Hawley et al., 1997). This is typically achieved through an exercise taper with the intake of large quantities of dietary CHO intakes before an event by endurance athletes (Bussau et al., 2002; Hawley et al., 1997).

Recently, studies have examined the effects of a 3-day CHO depletion followed by a 24-48 hours CHO loading protocol on body composition in male bodybuilding (de Moraes et al., 2019; Schoenfeld et al., 2020). De Moraes et al., (2019) demonstrated a 3% increase in BM, limb circumferences and muscle thickness of the upper arms using a stadiometer, tape measures and ultrasound equipment, respectively. Similarly, Schoenfeld et al., (2020) showed an increase in muscle thickness of 5% in the upper extremities and ~ 2% in the lower extremities in a case study of a male bodybuilder using ultrasound assessments. Increased muscle thickness, as confirmed by ultrasound assessments, may be visually noticeable to judges (de Moraes et al., 2019). Nevertheless, Schoenfeld and colleagues (2020) used an ultrasound method validated in 77-years healthy individuals (Reeves et al., 2004) on unstandardised body sites (Störchle et al., 2017). It is therefore uncertain if competition strategies such as CHO manipulation work effectively and are meaningful from an aesthetic standpoint for an FP athlete. Future research should verify these findings through well-designed randomized controlled trials that employ objective markers and compare a standard CHO intake with a CHO loading protocol. Moreover, the prevalence of use and effects of CHO depletion followed by loading (combined with other practices including fluid and salt manipulation) on physiological biomarkers FP athletes, is yet to be investigated.

2.10 Endogenous total body water balance and compartmental distribution: The effects of water loading on the human body

In parallel, with CHO depletion, FP athletes typically perform water loading (Chappell et al., 2017; Escalante et al., 2021), which entails increasing water intake to about four times greater than normal intake during the week and then reducing the day before the competition. This is aimed at encouraging polyuria in the belief that it may reduce total body water (TBW) (Nunes et al., 2021) and maximise the appearance of muscularity. Water makes up roughly 60% of the average woman's BM (TBW) (Jéquier & Constant, 2010). Total body water is divided into intracellular water (ICW) which is contained in the cytosol within various cell structures (Ritz et al., 2008) and extracellular water (ECW) which is the interstitial (fluid allowing movement between cell membranes), intravascular (blood plasma/lymph) and transcellular fluids (smallest component of ECW and includes cerebrospinal, synovial joint and gastrointestinal and lung spaces) (Seifter & Chang, 2017) (Figure 2.2). Both ICW and ECW can be manipulated to reduce TBW, enhancing skeletal muscle definition and minimising abdominal bloating for a smaller waistline (Escalante et al., 2021). Moreover, the super-compensation of glycogen (from CHO loading) causes an osmotic effect that pulls the subcutaneous ECW into the muscles, maximising the muscle volume from increases in ICW (Shiose et al., 2016).

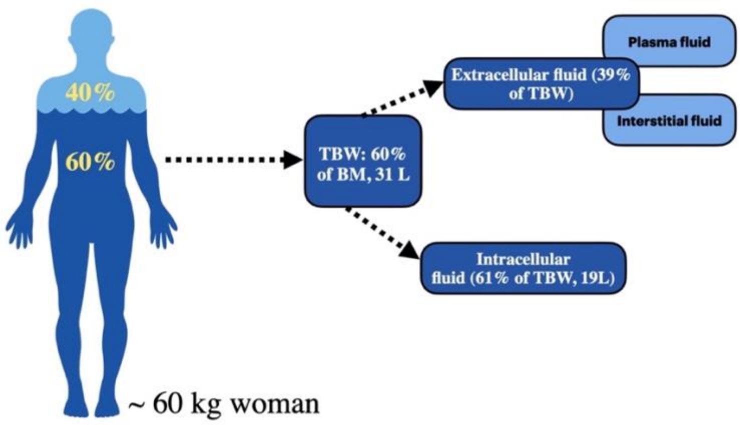

Figure 2.2 *— Compartmental distribution of endogenous TBW in a ~60kg woman (Drawn by the author using information from Escalante et al., 2021; Ritz et al., 2008; Rodriguez-Giustiniani et al., 2021).*

Maintaining fluid and electrolyte homeostasis involves coordinating various inputs and outputs, including neural pathways and integrative centres in the brain and peripheral regulation (Rodriguez-Giustiniani et al., 2021) (Figure 2.3). Dehydration is the loss of TBW, which can occur via active (exercise-based) and/or passive (non-exercise-based) methods such as sweating in a sauna (Hew-Butler et al., 2018). These losses can also be characterised as hypertonic (loss of endogenous TBW only, which increases osmolality), isotonic (concurrent loss of endogenous TBW and osmolality) or hypotonic (reducing plasma osmolality content which dilutes exogenous TBW) (Grandjean et al., 2003). These processes can result in health risks for FP athletes like hyponatremia (an excess of endogenous TBW due to low osmolality <135 mmol/L via hyperhydration) and/or hypernatremia (a reduction in endogenous TBW due to high osmolality >145 mmol/L via hypohydration), leading to symptoms such as nausea, vomiting, coma and even death (Adrogué & Madias, 2000a; Garigan & Ristedt, 1999).

Kidneys play a vital role in maintaining fluid and electrolyte balance, emphasizing the need to assess renal function in physique athletes during the pre-competition phase. A water deficit triggers two hypothalamic osmoreceptors in the brain, one regulating drinking behaviour (thirst) and the other controlling renal function. Such stimulus reduces the renin-angiotensin-aldosterone system response, lowering sodium excretion and increasing the secretion of arginine vasopressin (antidiuretic hormone) from the pituitary gland, which in turn alters the kidney's water reabsorption (Rodriguez-Giustiniani et al., 2021). This increases the ionic concentration of the ECW compartment (*i.e.*, increased osmolality, decreased plasma volume) and draws water from the ICW compartment (Rodriguez-Giustiniani et al., 2021) causing a fluid-electrolyte homeostasis disruption. Conversely, excess water has the opposite effect (Rodriguez-Giustiniani et al., 2021), reducing the ionic concentration of body water (*i.e.*, reduced osmolality and increased plasma volume) (Rodriguez-Giustiniani et al., 2021), which also disrupts fluid-electrolyte homeostasis.

From a physique sports perspective, minimising the extracellular interstitial fluid that surrounds the cells, specifically subcutaneous water, while also preserving or increasing the ICW may maximise muscle definition and skin tightness (the skin is pulled firmly against muscle with minimal signs of subcutaneous water) (Nunes et al., 2020; Escalante et al., 2021). Yet, this could represent a challenging and risky task because of the difficulty in balancing (loading and restricting simultaneously) water/sodium intakes to obtain these results (Escalante et al., 2021).

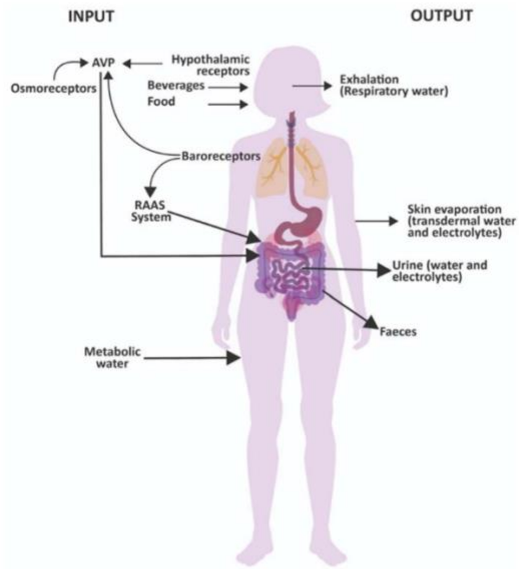

Figure 2.3*—Normal regulation of fluid and electrolyte balance illustrating usual processes for gain in body water (INPUT) and loss of body water (OUTPUT) with stimulation of hormonal controls of fluid and electrolyte regulators via arginine vasopressin release and activation of the renin-angiotensin-aldosterone system (Source: Rodriguez-Giustiniani et al., 2021; Reused with permission).*

2.11 Methods to measure hydration status

Health problems such as hyponatremia and hypernatremia in individuals manifest from attempting to water load or manipulate salt, and both practices are typically experimented in physique sport athletes during the final few days before competition (competition week) (Chappell & Simper, 2018; Shephard, 1994). As such, it remains crucial to assess hydration biomarkers in physique athletes. Assessment of hydration can be performed using a variety of non-invasive and invasive methods measuring both or either intracellular water content or extracellular water content.

Within laboratory and field settings common hydration assessment methods include changes in BM and TBW via bioelectric impedance, although these may not be reliable or valid (Zubac et al., 2018). Other methods include urine osmolality, urine specific gravity and urine colour, plasma osmolality and plasma sodium. Previous studies have prescribed definite ranges of hydration with indicative biomarkers of hypohydration and hyperhydration (Table 2.2) (Oppliger & Bartok, 2002; Shirreffs & Sawka, 2011). These reference ranges allow practitioners to crosscheck whether their athletes are at health risk. In a recent study, 55% of 318 collegiate athletes (193 females) were classified as hyperhydrated using urine indices, but this did not reflect similar outcomes in serum indices (*e.g.*, serum [Na^+]) (Hew-Butler et al., 2018). This discrepancy is likely to reflect the differences between using physiologically regulated (blood tonicity) versus non-physiologically regulated (urine concentration) variables within a normal range to define clinical extremes of fluid imbalance (Hew-Butler et al., 2018). In agreement, inaccuracy and high variability of TBW and urine indices (in isolation) for hydration assessment have previously been reported during unstandardised weight loss in combat sport athletes (Fernández-Elías et al., 2014; Zubac et al., 2018). As such, to increase accuracy and reliability for the assessment of hydration status, practitioners would benefit from using more than one method (Zubac et al., 2018). Despite highlighted measurement issues, no research to this date has investigated hydration indices in FP athletes during competition week (in which FP athletes manipulate sodium and water intake), and as such it is unknown whether these athletes are at risk of clinically hypo- or hyperhydration. Thus, Chapter 5 (study 3) offers insights into water loading practice and the impact on multiple biomarkers of hydration in a single case study during competition week.

Table 2.4: *Guidelines of dehydration via hypohydration/hyperhydration biomarkers. (Source: Adapted from (Fogarty & Loughrey, 2017; Hew-Butler et al., 2018; Shirreffs & Sawka, 2011).*

Measurement	**Practicality**	**Hypohydration marker**	**Hyperhydration marker**
TBW via BIA	**Low**	>2% of BM	NA
Serum [Na^+]	**Medium**	>145 $mmol.L^{-1}$	<135 $mmol.L^{-1}$
Posm	**Medium**	>290 $mOsmols \cdot kgH2O^{-1}$	<280 $mOsmols \cdot kgH2O^{-1}$
Uosm	**High**	>700 $mOsmols \cdot kgH2O^{-1}$	<250 $mOsmols \cdot kgH2O^{-1}$
Usg	**High**	1.020 $g.ml^{-1}$	1.012 $g.ml^{-1}$
BM	**High**	>2% of BM	NA

TBW denotes total body water. NA denotes not available; Usg denotes urine specific gravity, Uosm denotes urine osmolality, Posm denotes plasma osmolality, Na^+ denotes sodium concentrations. BM denotes body mass.

2.12 Health implications for the female physique athlete

Physique athletes typically reduce their TEI to induce gradual weight loss over a prolonged period of time (typical pre-competition phase is 12-24 weeks, Table 2.1), and progress towards acute weight loss methods, such as restrictive diets (energy availability [EA] < 45 kcal·kg^{-1} FFM·day^{-1}, where FFM = fat free mass), in the latter stages of the pre-competition phase (Fagerberg, 2018). As such, FP athletes face major health-related challenges in the attempt to reach and maintain a lean body composition.

2.12.1 The female athlete triad and relative energy deficiency in sport (RED-S) frameworks

In the mid 1990's, the American College of Sports Medicine (ACSM) (Otis et al., 1997) documented a position stand on an area of great medical concern in active girls and women with lean physiques; the triad of DE, amenorrhea and osteoporosis which was later defined as The Female Athlete Triad (The Triad) (Yeager et al., 1993) (**Figure 2.4).** An updated version was published in 2007 (Nattiv et al., 2007) for an enhanced understanding of the area (based on updated research). The work by Nattiv et al (2007) explained how the Triad is an interrelated continuum of EA, menstrual function and bone mineral density in which the athlete can move along the continuum at different rates depending on dietary and exercise behaviours (with or without an ED). As such, it was established that DE is no longer considered as a criterion of the Triad and LEA can occur unintentionally and intentionally. Furthermore, subclinical menstrual disorders were added to the revised statement of the Triad (De Souza et al., 2014).

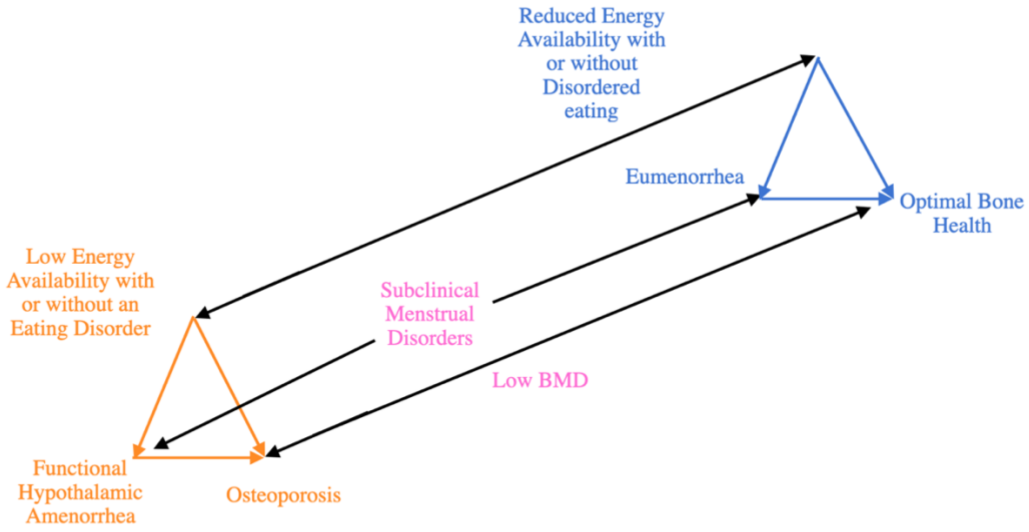

***Figure 2.4** —Continuum of inter-related components of the female athlete triad, which are energy availability, menstrual function and bone health. The athlete transitions along the lines between optimal health, subclinical and clinical conditions at different rates depending on dietary and exercise behaviours. Redrawn from De Souza et al., (2014).*

In 2014, the IOC released a consensus statement introducing the syndrome, RED-S, a framework which was referred to as 'beyond the female athlete triad' and included additional health and performance-related factors and which can affect both female and male athletes (Mountjoy et al., 2018). While the Triad and RED-S still coexist, RED-S is different from the Triad and is viewed as broader in scope. The RED-S was updated in 2018 to include research that has examined the syndrome in recent years, and has become an accepted framework to examine physiological functioning, general health and performance related consequences from LEA in athletes (Mountjoy et al., 2018). The RED-S framework represents twenty health and performance related consequences negatively affected by LEA (Mountjoy et al., 2018) (**Figure 2.5).** Although RED-S is a contemporary topic among researchers and practitioners, the true prevalence and research supporting the proposed consequences associated with LEA is only in its infancy and many areas still lack scientific support including mood states, cardiovascular health, gastrointestinal health and metabolic health (Mountjoy et al., 2018 and Williams et al., 2019).

There is a paucity of data investigating LEA and its effects in FP athletes, and therefore more research is warranted. To date, only two studies have investigated symptoms of RED-S are recent clinical trials (n = 27 and 25 FP athletes, respectively) (Hulmi et al., 2017; Mathisen et al., 2019) with data collected over three time-points (baseline, during pre-competition and post-competition phases). Thus, more studies are necessary to examine the chronic symptoms of RED-S in FP athletes. Additionally, considering the prolonged period of weight loss utilised by this population it might be tempting to suggest FP athletes are at risk for LEA and associated health consequences. However, this is warranting further investigation. Readers are directed to section 2.11.2 (published narrative review) for further information on the current evidence of RED-S symptoms in FP athletes.

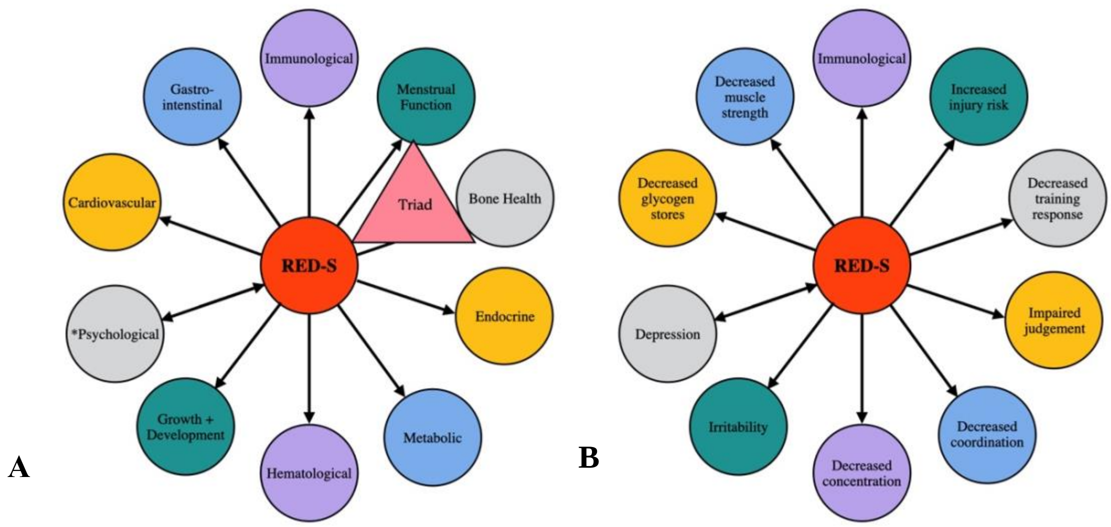

***Figure 2.5** —Illustrates the health (A) and performance (B) consequences of RED-S. *Psychological health which can be the consequence or the cause of RED-S (Redrawn by the author using information from Mountjoy et al., 2018).*

2.12.2 Reduced energy availability in female physique athletes

Current literature on FP athletes has documented prolonged periods of LEA, specifically during the pre-competition phases. Halliday and colleagues (Halliday et al., 2016) showed that during a 20-week pre-competition phase, the estimated mean EA was categorised as low in the initial (27.9 kcal.kg^{-1} FFM.day^{-1}) and latter (23.3 kcal·kg^{-1} FFM·day^{-1}) stages of the phase, respectively. In this study (Halliday et al., 2016), TEI and exercise energy expenditure (EEE) were self-reported and reproductive function was not measured. Similarly, (Tinsley et al., 2019a) documented caloric intakes of between 18.2 and 31.1 kcal.kg^{-1} FFM·day^{-1} in an FP athlete (during two different pre-competition phases) indicating further caloric restriction (Manore, 2015). Although EA was not objectively quantified, the authors estimated that the athlete fell below the threshold of EA for the maintenance of normal physiological function based on TEI and body composition data. Self-report research designs are not uncommon in the literature on physique athletes and, as such should be interpreted with caution (Fagerberg, 2018). Therefore, EA data in FP athletes remains questionable considering the lack of sensitive and relevant screening tools (Heikura et al., 2018). As a larger sample study, Mathisen and colleagues (2019) assessed the symptoms of RED-S in 25 Scandinavian FP athletes and 26 female references (non-competing females) across three time-points during a competitive season and found that manifestation of RED-S symptoms which persisted at the post-competition time-point. However, Mathisen et al., (2019) did not measure EEE directly (for example via portable indirect calorimetry and heart rate devices or metabolic equivalents) to calculate EA. Some athletes also submitted diet plans prescribed by their coaches rather than recording intakes at the time of the food/drink consumption (*e.g.*, completing a food diary). Collectively, without an accurate assessment of EEE and habitual EI, it is difficult to estimate EA or the risk of RED-S in FP athletes. Furthermore, the drop in measurements of RMR and HR are well characterised during energy deficiency (Strock et al., 2020). Therefore, aforementioned studies highlight that FP athletes may induce sub-optimal EA and shows the importance for future studies on this topic to utilise more robust measures of TEI and EEE as well as indices associated with RED-S in order to accurately evaluate EA (Elliott-Sale et al., 2018; Fagerberg, 2018).

2.12.3 Nutrient deficiency

Bodybuilding diets are traditionally characterised as restrictive and monotonous, as they often limit food variability (Kleiner et al., 1994). As a consequence, compromised micronutrient status is often observed in the pre-competition phase among FP athletes (Slater & Phillips, 2011). Calcium, iron, zinc and sodium intakes have been shown to decrease significantly, to nearly two-thirds (~ 67%) of the Recommended Daily Allowance (RDA) (Newton et al., 1993; Walberg-Rankin et al., 1993) in the absence of dietary supplements during the pre-competition phase. These results may be attributed to restricted EI combined with the elimination of sodium and dairy products from the diet (Steen, 1991). Considering that weight loss trends/dietary fads typically change over time, it is worth noting that the applicability of the aforementioned studies might be limited.

More recently, Ismaeel et al., (2018) showed that FP athletes who used extreme restrictive eating patterns (*i.e.*, monotonous meals with limited food selections, and little variability among and within food groups) consumed significantly less protein (123 ± 23 g *cf.* 65 ± 16 g, $p = 0.02$), sodium (4,060 ± 397 mg *cf.* 2,636 ± 1,028 mg, $p = 0.03$), vitamin E (10 ± 2 mg *cf.* 6 ± 1 mg, $p = 0.03$) and vitamin C (170 ± 47 mg *cf.* 66 ± 27 mg, $p = 0.02$) than athletes who permitted dietary flexibility. These differences may be caused by the large variation in TEI (1,965 ± 259 kcal·day^{-1} *cf.* 1,455 ± 541 kcal·day^{-1}) between these two groups (those who practised macronutrient-based dieting *versus* those who practised strict dieting). While the study (Ismaeel et al., 2018) included dietary supplements in the micronutrient analysis, it did not specify whether individuals were in the pre-competition or off-season phase. Nevertheless, these results identify potential risks for deficiencies in essential nutrients for FP athletes, which could suppress the immune function and cause increased susceptibility to illnesses and infections, especially for those engaging in restrictive eating patterns (Sundgot-Borgen & Garthe, 2011a). As the majority of studies assessing micronutrient status have also used self-report methods (Ismaeel et al., 2018; Kleiner et al., 1994; Newton et al., 1993; Walberg-Rankin et al., 1993; Walberg & Johnston, 1991) it is prudent that future measures are clarified using biomarkers in blood or urine samples. As such, biomarkers of micronutrients were identified in Chapter 5 (Study 3) in different phases of a competitive season of a single FP athlete to objectively detect adequacy or deficiency.

2.12.4 Menstrual irregularities, endocrine effects and bone health in female physique athletes

Many active women with LEA develop various forms of reproductive dysfunction, including oligomenorrhea, amenorrhea and luteal phase defects (Manore, 2015).

Low energy availability causes alterations in the hypothalamic-pituitary-ovarian axis, namely altered secretion of luteinizing hormone and follicle stimulating-hormone (pulsatility), which subsequently reduces oestrogen production. The final consequence is typically described as functional hypothalamic amenorrhea (West, 1998). Previous research has shown that 82-86% of females (non-contraceptive users) who entered at least one physique competition were either oligomenorrheic or amenorrheic (Walberg-Rankin et al., 1993; Walberg & Johnston, 1991). Similarly, previous studies have also observed amenorrhea (Halliday et al., 2016; Hulmi et al., 2017; Petrizzo et al., 2017; Rohrig et al., 2017), with some reporting delays in menstruation of up to 71 weeks post-competition (Halliday et al., 2016; Kleiner et al., 1994).

Changes to reproductive and metabolic hormones in FP athletes have been observed in the pre-competition phase, including decreases in oestradiol, testosterone, thyroid stimulating hormone, triiodothyronine (T3) and leptin (**Table 1.1).** These hormones were normalised within 4 - 16 weeks post-competition, when supported by an increased intake of protein (~ $2.g{\cdot}kg^{-1}{\cdot}day^{-1}$) and greater EA (Hulmi et al., 2017; Trexler et al., 2017) with the exception of serum T3 and testosterone (Hulmi et al., 2017), which were only partially recovered 12-16 weeks after competition. As such, the suppression of these key metabolic hormones persists further into the recovery phase. The need for greater EI may be necessary for an earlier hormonal recovery (without alteration of the exercise regimen) as previously described by Loucks & Heath (1994) and shown in a randomised controlled trial (Souza et al., 2021). More longitudinal data is required on endocrine and metabolic to better understand the time-course for full restoration.

Irregular menstrual cycles are often used as a surrogate marker of long-term LEA; however, the use of hormonal contraceptives may mask the effect of LEA on menstrual function/bleeding (Heikura et al., 2018). Hormonal contraceptives provide negative feedback to the hypothalamus and pituitary glands, leading to suppression of follicle stimulating-hormone, luteinizing hormone and gonadotropin-releasing hormone, and continuous down-regulation of endogenous oestrogen and progesterone (Elliott-Sale et al., 2013). Previous studies in FP athletes have failed to investigate female sex hormones (*i.e.*, oestrogen and progesterone), did not include hormonal contraceptive users (Halliday et al., 2016; Rohrig et al., 2017; Tinsley et al., 2019a) or grouped all oral contraceptive users together (Hulmi et al., 2017; Mathisen et al., 2019), making the interpretation difficult. Considering the high prevalence of hormonal contraceptive use (Hulmi et al., 2017), there is great concern that FP athletes, who are experiencing chronic LEA, are going undetected, as hormonal contraceptive use maintains regular menstrual cycles. To this end, there is a need for studies to determine whether the FP athletes, who are using hormonal contraceptives, are at increased risk of endocrine dysfunction.

Although it is not unusual for bone mineral density to be compromised during calorie restriction and reduced BM, the minimal negative changes in bone mineral density (Δ-1.3-1.4%) in a 12-32 week pre-competition phase (Hulmi et al., 2017; Petrizzo et al., 2017; Ploeg et al., 2001) and spine z-scores −0.04 (−0.52, 0.43) (Mathisen et al., 2019) may be explained by the high-impact and weight-bearing activities performed in their training regimens (Zanker et al., 2004). As a result, this may have served to retain bone-mineral density compartment (Layne & Nelson, 1999).

2.12.5 Weight cycling

FP athletes often experience rapid weight gain following competitions (Andersen et al., 1995; Walberg-Rankin et al., 1993) with one study reporting uncontrollable binge eating behaviour, reflecting a hyperphagic effect to intensive weight loss protocols (Trexler et al., 2017). This practice is commonly known as 'weight cycling' (*i.e.,* repeated cycles of weight loss and regain within short timescales) and potentially problematic in later life in terms of increasing the risk of developing obesity and cardiometabolic disease (Miles-Chan & Isacco, 2020; Saarni et al., 2006). Previous research have shown unfavourable metabolic changes, including a decline in measured resting metabolic rate (RMR) relative to FFM (reduced 4.0-4.9 $kcal \cdot kg^{-1}$ $FFM \cdot day^{-1}$ from baseline) (Rohrig et al., 2017; Tinsley et al., 2018) during pre-competition phase. Additionally, females have shown weight regain of up to 8.6 kg at 4 weeks post-competition refeeding (Walberg-Rankin et al., 1993). The RMR suppression is possibly induced by the dietary restriction during weight loss resulting in alterations in leptin levels, thyroid status and sympathetic nervous system activity (Stiegler & Cunliffe, 2006). Conversely, recent case studies have shown that some FP athletes use a "reverse dieting" technique, in order to avoid rapid FM regain during the recovery phase (Trexler et al., 2014). This strategy requires athletes to slowly increase their EI in an effort to limit any rapid increases in FM while reversing the physiological adaptations including RMR from the pre-competition (Trexler et al., 2014). However, the effort to "reverse" (*i.e.,* slowly increase) EI requires considerable discipline to curb the increases in appetite sensations (Greenway, 2015) and therefore the authors speculate, whether such a strategy is achievable. Future research on “reverse dieting” technique in the recovery phase is warranted.

2.12.6 Eating behaviours: Disordered eating /Eating Disorders

Considering that appearance is a major criterion to judge performance of FP athletes, the increased risk of DE/ED in this population is perhaps unsurprising. Important risk and trigger factors of poor eating habits in FP athletes may include the focus on aesthetic appearance as the primary performance marker in competition (Sundgot-Borgen & Torstveit, 2004), the peer/media pressure which can elicit body dissatisfaction (Hausenblas et al., 2013), and the influences from coaches with inadequate nutrition knowledge (Sundgot-borgen, 1994). There is also evidence that FP athletes are particularly vulnerable to DE/ED and body image dissatisfaction because of the preoccupation with being muscular and lean (Devrim et al., 2018).

For example, a cross-sectional study by (Walberg & Johnston, 1991) compared 12 aspiring and retired FP athletes with 103 recreational weight-lifters on the Eating Disorder Inventory. Results revealed that FP athletes had significantly greater food obsessions (67%), uncontrolled urges to eat (58%) and felt more terrified of becoming fat (58%; all $p < 0.05$). The use of laxatives, for weight loss, (17% *cf.* 15%) and binge eating (50% *cf.* 62%) were similar between the groups. In another study, Andersen et al., (1998) reported that ten out of twenty-six FP athletes experienced binge eating episodes in the recovery phase and eighteen out of twenty-six FP athletes displayed body and weight dissatisfaction, reiterating that there is a high risk of eating and body image-related problems within the sport (Pope et al., 1997). Nevertheless, the small sample size and the lack of any comparative group analysis by Andersen et al., (1998) somewhat limits the interpretation. More recently, Whitehead et al., (2020) reported that approximately half of the participants were identified with DE (46.6%), independent of division, with 27.3% exhibiting clinical and 19.3% having subclinical DE. A reasonable explanation for a high prevalence and occurrence in aesthetic sports may be the high sociocultural expectations and pressures to be lean and/or a specific BM (Kong & Harris, 2015). To support this, Mathisen & Sundgot-Borgen (2019) showed that FP athletes exhibited higher levels of DE and body shape concerns compared to recreationally active athletes, with significant differences between groups on drive for leanness and muscularity at all time-points. This may suggest that strict dieting and excessive exercise regimens cannot be sustained for prolonged period and as such body shape declines from the idealised body image.

Aforementioned studies have however used self-reported questionnaires with no interviews to obtain a greater and deeper understanding of these changes of mental health prompted by the sport. Furthermore, it is difficult to capture sensitive data using questionnaire methods concerning mental health and well-being without a confirmatory interview (Andersen et al., 1998). Athletes may be anxious of revealing inappropriate eating practices in fear of being negatively judged, which could prevent honest disclosure. Nevertheless, there is a plausible link between participation in physique sports and DE behaviours. Further research is warranted to explore the psychopathological and behavioural outcomes in these athletes. Understanding the experiences and perceptions of weight management and eating behaviours across the pre-competition, recovery and off-season phases might be of particular importance. Using validated screening tools to detect DE and EDs and follow-up interviews will allow researchers to collect comprehensive data that could inform practice. In chapter 3 (study 1) and Chapter 6 (Study 4) assessment of weight management and eating behaviours and further understanding of their experiences across their sporting career were therefore assessed.

2.12.7 Recovery from energy deficiency: Potential implications for rebound hyperphagia

Early studies (Benedict, 1907; Benedict, 1919) assessing the recovery from energy deficits, observed post-starvation BM overshoot (*i.e.*, BM increasing beyond baseline values) during a period of refeeding in fasters. Later, the Minnesota Starvation Experiment by Keys and colleagues (1950) conducted a 24-week energy deficit period (where BM was reduced by 25% via a 40% reduction in EI). During the recovery period, which included an additional 400, 800, 1200 or 1600 $kcal.day^{-1}$ BM markedly overshot (>10% above baseline) with the majority of this weight regain was due to accumulation of FM (Keys et al., 1950). This phenomenon has been described as ‘post starvation obesity’ or ‘rebound hyperphagic response’ and is driven by hunger-appetite drive (Dulloo et al., 2015). More recent studies in American male recruits (Friedl et al., 2000; Nindl et al., 1997; Young et al., 1998) found that eight to nine weeks of energy deficit resulted in a 12% BM loss. However, at four weeks post-energy deficit period BM increased by 3-7% with fat overshoot by 40-60% above baseline values.

Similar observations have been reported in weight-sensitive elite athletes (Langan-Evans et al., 2020; Morehen et al., 2021). For instance, a recent case study (Morehen et al., 2021) of a professional boxer who competed in 11 competitions over 5 years, with relative weight loss for each competition averaging 13.9 ± 2.0% (range: 11.3-

18.2%) led to progressive increases in FM (*i.e.*, 12.5 and 16.1 kg for Contests 1 and 11, respectively) and reductions in FFM (*i.e.*, 69.8 kg and 67.5 kg for Contests 1 and 11, respectively). This highlights concerns with weight cycling in weight-sensitive athletic groups. The psychological and physiological regulation of hyperphagia is complex and potentially mediated by the hypothalamic neuroendocrine axis. Currently, it is yet to be recognised as a potential issue in physique sports despite the culture of long-term dieting and weight cycling (Longstrom et al., 2020; Trexler et al., 2017).

It is speculated by many researchers that binge-eating (extreme desire for food occurs after considerable weight loss) develops as a consequence of hyperphagia (Dulloo et al., 2015; Helms et al., 2019; Weyer et al., 2000). A longitudinal study on former athletes found that those who weight cycle, increased their BMI from age 20 to 60 years compared to those who did not (Saarni et al., 2016). There are also a number of cardiometabolic health markers that may be affected, including unfavourable levels of blood pressure, blood glucose, insulin and lipids associated with rebound hyperphagia (Dulloo et al., 2015; Miles-Chan & Isacco, 2020). Compromised psychological health caused by weight regain is likely to conflict with physique goals among FP athletes, leading to higher levels of DE, increased body shape concerns (Helms et al., 2019; Mathisen & Sundgot-Borgen, 2019) and mood disturbances (*i.e.*, depressive symptoms (Andersen et al., 1998). Ultimately, these health outcomes may encourage some athletes to resume dieting practices (potentially with more restrictive eating patterns than previously) in an attempt to return to their competition body composition (Helms et al., 2019). To further understand the personal and lived experiences of FP athlete and their subjective perceptions of weight management in their sporting career Chapter 6 (study 4) it was therefore important to interview a sample of FP athletes.

2.13 Participant recruitment in physique sports

FP athletes represent a difficult group of athletes to study. Previous studies have either been single-subject studies (Halliday et al., 2016; Petrizzo et al., 2017; Rohrig et al., 2017; Tinsley et al., 2019a) or small cohorts (Longstrom et al., 2020; Mitchell et al., 2017; Money-Taylor et al., 2021; Trexler et al., 2017). Whilst only four large sample size (25 - 348 participants) studies exist in FP athletes (Hulmi et al., 2017; Mathisen et al., 2019; Mathisen & Sundgot-Borgen, 2019; Whitehead et al., 2020), two of these are clinical trials funded by external parties (Hulmi et al., 2017; Mathisen et al., 2019; Mathisen & Sundgot-Borgen, 2019) whilst the larger sample size study was a cross-sectional study in Australia (Whitehead et al., 2020). There are several major pragmatic reasons for not having studied this group in larger sample sizes in the past. Firstly, the majority or FP athletes are amateur and self-fund their participation within the sport. This makes recruitment of this population challenging especially during the pre-competition phases and during the final week prior to competition as many of them are still working full time, have family commitments or would rather focus on the competition rather than attending a laboratory or have field-based research assessments performed. Moreover, a large number of athletes are normally excluded from research studies due to use of banned or performance-enhancing aids (de Moraes et al., 2019). Furthermore, participation numbers have been shown to decrease during studies due to withdrawal from competition (Mathisen & Sundgot-Borgen, 2019; Mitchell et al., 2018). Finally, FP athletes may not be comfortable revealing inappropriate eating and training behaviours in fear of being negatively judged, which could prevent honest disclosure, while others may fear disclosing strategies to other athletes and lose competitive advantage. It should also be noted that this unique athletic population is highly focused on self-chosen goals and are not typically pre-disposed to participate in research that does not directly contribute to aesthetic enhancement for competition success (Bloodworth & McNamee, 2010). The difficulties with recruitment may explain the scarcity of studies in FP athletes, as well as a potential aversion of this demographic to participate in scientific research. Given the significant outcomes, with regards to practices, body composition, health and well-being, further research into this group of athletes is likely to identify practical strategies capable of being translated into other populations engaging in weight loss. As such, researchers should consider future recruitment strategies carefully, including but not limited to: time commitment during testing, rewards/benefits provided back to participants for participation and patient public involvement when designing study methods to allow larger sample sizes, minimum withdrawal and higher response rate and interest.

2.14 Conclusions and future research

The ultimate determinant of competitive success in physique events is a high degree of muscularity and minimal FM. As such, FP athletes engage in both prolonged energy restriction and intensive training regimens in order to meet these demands. Some FP athletes may be vulnerable to chronic LEA and associated physiological and psychological health effects, even during the recovery phase. Despite an increased participation in physique events, there is paucity in the literature on FP athletes. Future research should therefore:

i) identify the weight management strategies and DE/ED behaviours of FP athletes, in order to determine the risks of LEA in this population;

ii) explore such strategies using a qualitative approach, to enable FP athletes to express and elaborate on their experiences of weight management, eating behaviours and psycho-physiological health implications;

iii) investigate endocrine and micronutrient changes in FP athletes using objective biomarkers, to assess whether these individuals are in chronic states of LEA throughout the season;

iv) develop effective, safe and evidence-based nutritional recovery guidelines to minimise any long-term health implications.

[redacted] 3.Weight Loss Practices and Eating Behaviours among Female Physique Athletes: Acquiring the Optimal Body Composition for Competition

This study has been published in *PLOS ONE* journal article.

Alwan N et al., (2022). Weight Loss practices and eating behaviours among female physique athletes. Acquiring the optimal body composition for competition. *PLOS One* 17(1); e0262514. Doi: https://doi.org/10.1371/journal.pone.0262514

An abstract was published from this chapter (using a sub-sample of participations) in *International Journal of Sport Nutrition and Exercise Metabolism* by Nura Alwan, Samantha L. Moss, Kirsty J. Elliot-Sale, Ian G. Davies, and Kevin Enright (2019).

3.1 Introduction

Despite, considerable growth in physique sports in recent years (Section 2.1, Section 2.3), little is known about the weight loss and eating behaviours in FP athletes. Traditionally, bodybuilding was the only division available for women, however in recent years, further divisions have been introduced to facilitate females with differing physique traits and aspirations (Whitehead et al., 2020) including Bikini Fitness and Figure physique athletes (Alwan et al., 2019). Female physique athletes are solely judged on aesthetic appearance (Helms et al., 2014) and have been reported to engage in practices associated with prolonged and acute weight loss, many of which may be detrimental to health and aesthetic appearance in competition.

Current practices to acquire optimal body composition for competition are, at present, not well-understood. Consumption of small and frequent meals, combined with rigorous training practices for approximately 11-32 weeks pre-competition have been documented (Chappell et al., 2018; Halliday et al., 2016; Petrizzo et al., 2017; Rohrig et al., 2017). However, others show problematic behaviours including extreme dieting, intentional fasting, laxative use, and self-induced vomiting (Andersen et al., 1998; Whitehead et al., 2020). Furthermore, in the final 7-days prior to competition, also known as 'peak week', there is an emphasis on CHO, fluid, and salt manipulation such as CHO depleting/loading, salt loading/depleting and water loading/tapering practised simultaneously (Barakat et al., 2022; Chappell & Simper, 2018; Mayr et al., 2012; Shephard, 1994) (see literature review, section 2.7). Previous studies (Hulmi et al., 2017; Mathisen et al., 2019) have not captured the frequency of weight loss and dietary practices used for competition (*e.g.*, laxatives, water loading and salt manipulation). Delineating the methods used and possible psychological and physical health implications are important, so that FP athletes can be provided with targeted support that enables safe and effective manipulation of body composition. Recent research in female and male combat sport athletes (Artioli et al., 2010) and powerlifters (Nolan et al., 2020) report coaches to be the primary influence on weight management practices. As reported in Chapter 6 (study 4) from qualitative data, there is reliance on coaches for support and guidance pre- and post-competition. However, at present, studies on key influencers in FP athletes are limited. Identifying key influencers of practices will offer insights into the reliability of their sources.

Engaging in any dieting or weight loss may put athletes at risk of RED-S and associated health consequences such as menstrual dysfunction and poor psychological health (for a review see (Mountjoy et al., 2018)). Repeated engagement with these practices may increase the likelihood of DE and ED (Sundgot-Borgen & Garthe, 2011). Disordered eating begins with voluntary energy restriction, leading to chronic dieting, poor body image, and frequent weight fluctuations using high-risk weight management strategies, ultimately increasing the risk of clinical ED – known as the continuum model of DE (Sundgot-Borgen & Torstveit, 2010). Although it is important to investigate DE and ED in FP athletes, limited studies have been conducted in physique sports (Mathisen & Sundgot-Borgen, 2019) especially with regards to assessing the risk between experience levels and/or divisions (Whitehead et al., 2020).

Experience level could influence the likelihood of athletes engaging in aggressive weight loss practices and subsequent DE/ED development (Goldfield et al., 1998). For example, athletes with greater experience may be placed under increased pressure to become leaner from self-expectations and other competitors (Kong & Harris, 2015), while others suggest that experienced athletes might better manage expectations (Hurst et al., 2000). Moreover, the division-specific body composition requirements for competition (Alwan et al., 2019) could also influence strategies for weight management and development of DE/ED. Nevertheless, the influence of both experience level and division remains unexplored.

This study aimed to investigate the weight loss history, practices and influential sources of dieting during the pre-competition phase in a large cohort of FP athletes. A secondary aim was to determine the extent of DE symptoms among FP athletes, in order to identify whether these athletes were at risk of developing an ED. It was hypothesised that those athletes competing in the Figure division and novice athletes would experience greater weight fluctuations, use acute weight loss practices more frequently and report more DE symptoms compared to Fitness athletes and experienced athletes. Based on previous data from weight-sensitive sports, it was also hypothesised that coaches would be the main influences on dieting and weight loss practices instead of qualified personnel (irrespective of division and experience).

3.2 Materials and methods

3.2.1 Recruitment and selection criteria

FP athletes were recruited from social media advertisement, forums, word-of-mouth, fitness centres and UK-based bodybuilding organisations (June 2017 to July 2018). Inclusion criteria were females aged 18-65 years and participation in a physique competition (previous 12 months). Exclusion criteria included previously diagnosed with an ED, had used, or were currently using, banned substances. By completing the survey, participants provided consent and where informed involvement was voluntary, anonymous and confidential. The study was approved by the University Ethical Review Board in the United Kingdom (17/TLA/003).

3.2.2 Study design

Using a cross-sectional research design, participants completed an anonymous online self-report survey (Bristol Online Survey© software 2013, Bristol, England) comprising two validated questionnaires (Rapid Weight Loss Questionnaire (RWLQ) (Artioli et al., 2010) and Eating Attitudes Test (EAT-26) (Garner et al., 1982) to assess weight loss history, practices and DE symptoms, respectively. Both questionnaires have been previously utilised in aesthetic and weight-sensitive populations with good sensitivity, specificity and excellent internal consistency (RWLQ: Cronbach's alpha = 0.98) (EAT-26: Cronbach's alpha = 0.90) (Garner et al., 1982; Artioli et al., 2010). For content validity, the survey was reviewed by two registered practitioners (Sport and Exercise Nutrition Register and Association for Nutrition), and pilot-tested by an experienced international FP athletes (+5 y competitive experience) (appendix 9.1, Chapter 9). Minor syntax, additional words/terminology and formatting modifications were made to the RWLQ questionnaire to ensure appropriateness for physique sports.

3.2.3 Participants

A total of 191 FP athletes accessed the survey, of which 178 (93%) completed it. Twenty FP athletes were excluded (due to not meeting the inclusion criteria and missing data) resulting in 158 FP athletes in the final analysis.

3.2.4 Rapid Weight Loss Questionnaire

Weight management was assessed using questions derived from the RWLQ, which comprises of 21 items and has three subscales: Participant's characteristics (*i.e.,* "*at what age did you start competing ? and "how many times did you compete in your last season?*"), weight and diet history (*i.e., "what is the most weight you have lost?" and "what is the most weight you have re-gained in the 7-days after competition?")* and weight loss behaviours (*i.e., "I use gradual dieting", "I use excessive exercise", "I skip 1 or 2 meals a day" and "I use water loading"*). FP athletes indicated agreement using a 5-point Likert Scale: "Never used" (0) and "Always" (4) (with a total score possible of 54 points) on weight loss behaviours questions. The RWLQ scoring system indicates the higher the score obtained, the more aggressive the weight loss behaviours. This questionnaire was selected because FP athletes are known to use weight as a reference for progression and use acute weight loss practices (Andersen et al., 1998). The degree of key influential sources of dieting derived from the RWLQ was also assessed ranging from "non-influential" to "very influential".

3.2.5 Eating Attitude Test-26

Eating attitudes and behaviours were assessed using EAT-26 (Garner et al., 1982) consisting of three subscales: Dieting (13 items), eating preoccupation (6 items) and oral control (7 items). This 26-item questionnaire asks about pathological eating behaviours and concerns about weight and is a widely used screening instrument for ED risk (Rosendahl et al., 2009). Participants rated their agreement with statements such as *"I find myself preoccupied with food*" and "*I am terrified of being overweight*". Responses were prepared on a 6-point Likert scale anchored by "never" (1), "rarely" (2), "sometimes" (3), "often" (4), "usually" (5) and "always" (6). Additionally, the frequency of pathogenic weight control methods (PWCM) including binge eating, self-induced vomiting and laxatives, diet pills and diuretics (water pills) use was assessed. The magnitude of PWCM, as a measure to control weight were assessed using the behavioural section of the EAT-26 (Garner et al., 1982). A total EAT-26 score >20 cut-off point is indicative of being at risk for ED. The magnitude of PWCM, as a measure to control weight (Figure 3.3), were assessed using the behavioural section of the EAT-26 (Garner et al., 1982).

3.2.6 Statistical analysis

Statistical Package for the Social Sciences v.23 (SPSS Inc, Chicago, IL) was used for analysis. Continuous data (participant characteristics, weight loss and diet history) was expressed as mean and standard deviations (mean±SD) with ranges, unless otherwise stated, whilst categorical data (frequency and the degree of influence of weight loss practices) were expressed as absolute numbers (n) and percentages (%). Continuous data was checked for the assumption of normality and equality of variances using Kolmogorov-Smirnov and Levene's test, respectively (Hoekstra et al., 2012). When normality was met, a two-way between subject's ANOVA compared the variability of mean values across; experience level (Hurst et al., 2000) and division (Fitness and Figure). Bonferroni post-hoc test was used for pairwise comparisons. Where the assumption of normal distribution was violated, the Mann Whitney test was used.

To assess relationships between the total EAT-26 score and the subscales scores of the EAT-26 and potential risk factors associated with weight history (*i.e.,* weight regain), Spearman's rank correlations (r_s) were used. In total, the study recruited from four groups: Bikini Fitness (*n*=107), Figure (*n*=42), Women's Fitness (*n*=6) and Physique athletes (*n*=3). Due to insufficient respondents from Women's Fitness and Physique athletes, divisions were grouped collectively into "Fitness" (Bikini Fitness and Women's Fitness) and "Figure" (Figure and Physique), owing to the similarities in preparation and proximity in body composition requirements. The significance level was set at P<0.05 for all statistical analyses.

3.3 Results

3.3.1 Participant characteristics

Participant characteristics are presented in Table 3.1, categorised into the following divisions: Fitness novice (Bikini Fitness and Women's Fitness with ≤1 year of competition experience; *n* = 62; 39%), Fitness experienced (Bikini Fitness and Women's Fitness with >2 years of competition experience; *n* = 53; 34%), Figure novice (Figure and Physique with ≤1 year of competition experience*; n* = 19; 12%) and Figure experienced (Figure and Physique with >2 years of competition experience*; n* = 24; 15%).

In total, 99% of respondents reported losing weight for past competitions and participating in 2±1 competitions (range: 1-8) in the previous season. Irrespective of division, novice athletes were younger (27±7 *vs.* 30±7 years, $F_{1,154}$ = 6.73, P=0.01), shorter (163.4±6.4 *vs.* 165.4±6.2 cm, $F_{1,154}$ = 7.74, P<0.01) and lighter than experienced athletes (53.8±4.9 *vs.* 56.1±5.8 kg, $F_{1,154}$ = 7.59, P<0.01). No main effect of division was identified (P >0.05).

Table 3.1: *Participant characteristics and weight loss experience for competition across divisions and experience.*

Athletes (n = 158)	Age (years)*	Height (cm)*	Most recent competition weight (kg)*	Times competed last season (n)	Age at first competition (years)	Typical diet length (weeks)	Competition level % (n)
Fitness Novice (n = 62)	27 ± 6 (18 - 45)	164.4 ± 6.5 (153 – 178.0)	53.7 ± 5.1 (45 – 65)	2 ± 1 (1 - 6)	26 ± 7 (17 – 45)	15 ± 4 (4 - 25)	R: 69.4 (43) N:21.0 (13) I:8.1 (5) PRO: 1.6 (1)
Fitness Exp (n = 53)	30 ± 7[a] (20 - 45)	165.4 ± 6.2[a] (152 – 175.3)	55.3 ± 5.4[a] (44 - 68)	2 ± 1 (1 - 6)	27 ± 7 (18 - 43)	14 ± 6 (2- 25)	R: 60.4 (32) N:18.9 (10) I: 11.3 (6) PRO: 9.4 (5)
Figure Novice (n = 19)	29 ± 7 (20 - 45)	160.1 ± 5.2 (149.8 – 170.0)	54.1 ± 4.2 (44.4 – 62.0)	3 ± 2 (1- 8)	28 ± 7 (19 - 45)	15 ± 5 (7 - 32)	R: 63.2 (12) N:31.6 (6) I:5.3 (1) PRO: 0 (0)
Figure Exp (n = 24)	32 ± 6[c] (23 – 44)	165.4 ± 6.5[c] (155 -178.0)	57.8 ± 6.5[c] (48.5 -70.0)	3 ± 1 (1- 6)	28 ± 6 (21 -42)	14 ± 3 (10 - 20)	R: 45.8 (11) N:29.2 (7) I: 20.8 (5) PRO: 4.2 (1)
Combined	29 ± 7 (18 – 45)	164.4 ± 6.4 (149.8 – 178.0)	54.9 ± 5.5 (44 – 70)	2 ± 1 (1 - 8)	27 ± 7 (17 - 45)	15 ± 5 (2 -32)	R: 62 (98) N: 22.8 (36) I: 10.8 (17) PRO 4.4 (7)

Values are presented as mean ± SD and include the range in brackets. R = regional, N = national, I = International, PRO = professional. **significant main effect between experience levels.* ^ = Typical diet length prior to competition. R = Regional level, N = National, I = International and PRO = Professional level athlete. Exp = Experienced physique athletes. [a] denotes significant difference from Fitness Novice, $P < 0.05$. [b] denotes significant difference from Fitness Exp, $P < 0.05$. [c] denotes significant difference from Figure Novice, $P < 0.05$. [d] denotes significant difference from Figure Exp, $P < 0.05$.

3.3.2 Weight loss history

Weight and diet history across divisions and experience levels, is presented in Table 3.2. Division had a main effect on absolute weight regain in the 7-days after competition (2.7±1.5 *vs*. 2.4±1.7 kg, $F_{1,151}$ = 4.65, P=0.03) and relative weight regain ($F_{1,149}$ = 8.07, P<0.01). No interactions were detected for absolute or relative weight regain in the 7-days after competition. Division and experience level had no effect on usual absolute and relative weight loss (P>0.05). There was a division by experience interaction for most weight loss ($F_{1, 152}$ = 4.38, P=0.03) with increases in absolute values from Figure novice athletes (8.4±2.4kg) to Figure experienced athletes (10.1±3.6 kg). The opposite was observed, however, between Fitness novice (10.0±4.3 kg) to Fitness experienced (8.8±4.7 kg). There were no differences for most weight loss in relative values. There was no main effect for division or experience level in competition week weight loss (P>0.05) but a significant interaction ($F_{1,136}$ = 4.46, P=0.04) was identified. Rapid weight loss (RWL) score showed no difference between division ($F_{1,153}$ = 1.10, P=0.30) nor between experience levels ($F_{1,153}$ = 1.10, P=0.30) and no interaction ($F_{1,153}$ = 0.02, P=0.90). Relative weight regain was weakly correlated with the total EAT-26 score (r_s = 0.21, P=0.01), subscales; dieting score (r_s = 0.20, P=0.01), and bulimia score (r_s = 0.20, P=0.01).

Table 3.2: *Female physique athlete (n=158) responses to weight loss and eating behaviour questions stratified by division and experience level.*

	Fitness Novice (n= 62)	**Fitness Exp (n = 53)**	**Figure Novice (n= 19)**	**Figure Exp (n= 24)**	**Overall (n = 158)**
#*Most weight lost (kg)?	10.0 ± 4.3 (0 -20)	8.8 ± 4.7[a] (1.5 - 21.0)	8.4 ± 2.4[a] (5 - 15)	10.1 ± 3.6[bc] (4 -20)	9.4 ± 4.2 (0 – 21)
Most relative weight lost (%)?	13.7 ± 6.2 (0 - 35.1)	15.0 ± 6.1 (6.0 - 34.4)	14.9 ± 4.4 (7.0 - 22.2)	16.0 ± 6.3 (2.8 - 28.2)	14.6 ± 6.0 (0 - 35.1)
***Weight usually regained in the week 7-days after competition (kg)?**	2.4 ± 1.7 (0.2 - 8.5)	2.3 ± 1.7 (0 – 8.0)	3.3 ± 1.6[a] (1.0 - 6)	2.3 ± 1.3 [b] (0 - 5.7)	2.5 ± 1.7 (0 - 8.5)
***Relative weight usually regained 7-days after competition (%)?**	4.1 ± 3.0 (0 - 15.9)	4.0 ± 2.7 (0.7 -14.0)	5.6 ± 2.8[a] (2.0 -11.4)	5.4 ± 3.2[b] (0.7 -14.7)	4.5 ± 3.0 (0 - 15.9)
Usual weight loss (kg)?	8.4 ± 3.9 (0 - 17.5)	7.6 ± 3.8 (1.5 – 21.0)	8.0 ± 1.9 (5.5 -12.7)	8.2 ± 3.7 (0 – 15)	8.0 ± 3.6 (0 -21)
Usual relative weight loss (%)?	13.0 ± 5.7 (0 - 25.9)	11.7 ± 4.8 (2.8 - 25.3)	13.0 ± 2.9 (9.7 -21.9)	12.7 ± 5.3 (0 - 21.1)	12.5 ± 5.1 (0 - 25.9)

#How much weight do you usually lose in competition week (kg)?	1.52 ± 1.02 (0 - 5)	1.46 ± 0.84[a] (0 - 4)	1.70 ± 1.34[a] (0 - 5)	1.25 ± 0.68[bc] (0 - 3)	1.48 ± 0.96 (0 - 5)
What was your last off-season weight (kg)?	63.7 ± 6.6 (50.0 - 82.0)	63.0 ± 8.3 (49.4 -83.0)	60.9 ± 5.8 (52.2 -70)	64.1 ± 6.2 (52 -79.0)	63.2 ± 7.1 (49.4 – 83.0)
RWLS score	22.3 ± 7.1 (7.3 - 48.2)	21.3 ± 7.3 (10 - 43.2)	23.4 ± 7.8 (13 - 45.7)	23.2 ± 8.7 (11.5 - 42)	22.2 ± 7.5 (7.30 - 48.20)
EAT-26 score	19.0 ± 12.6 (2.0 – 54.0)	17.3 ± 15.2 (0 - 55)	22.0 ± 12.7 (2 - 54)	18.2 ± 13.1 (1 – 54)	18.6 ± 13.5 (0 – 55)
EAT-26 score (≥ 20 cut off) (%)	38.8	36.1	42.2	21.0	36.8
EAT-26 score (< 20 cut off) (%)	60.5	63.2	58.0	79.4	63.5
Dieting score	11.2 ± 7.9 (0 - 33)	11.0 ± 10.2 (0-33.0)	12.8 ± 8.8 (1 - 33)	13.0 ± 13.6 (0-33)	11.2 ± 8.9 (0 - 33)
Bulimia and food preoccupation score	4.1 ± 3 .8 (0 -15)	3.2± 3.5 (0 - 14)	5.4 ± 3.6[ab] (1 - 12)	4.6 ± 4.9[b] (0 -13)	4.1 ± 3.7 (0 - 15)
Oral control score	3.4 ± 2.8 (0 -11)	2.8 ± 2.8 (0 - 10)	3.4 ± 3.1 (0 -10)	4.6 ± 4.2 (0-8)	3.1 ± 2.8 (0 -11)
No use of PWCM (%)	0	0	15	32	7.0

Use of 1 PWCM (%)	41	28.5	45	20	37.3
Use of 2 PWCM (%)	45.9	53.8	25	24	42.4
Use of 3 PWCM (%)	13.1	7.7	15	24	13.3

Values are presented as mean ± SD and include the range in brackets. *significant main effect between divisions, #division by experience interaction. [a] denotes significant difference from Fitness Novice, $P< 0.05$.[b] denotes significant difference from Fitness Exp, $P< 0.05$. [c] denotes significant difference from Figure Novice, $P< 0.05$. [d] denotes significant difference from Figure Exp, $P< 0.05$. Exp = Experienced physique athletes. RWLS = Rapid Weight Loss Score, EAT = Eating Attitude Test, PWCM = Pathogenic Weight Control Methods. Most weight loss is the most weight ever cut before a physique competition. Usual weight loss is the weight usually cut before a physique competition. Most relative weight loss is the percentage (of the individual's off-season weight) that was mostly cut for a physique competition. Usual relative weight loss is the percentage (of the individual's off-season weight) that is usually cut for a physique competition.

3.3.3 Weight loss methods and sources of influence

Frequency analysis of weight loss practices prior to competition is illustrated in Figures 3.1 and 3.2 (*n*=158). There were no associations between division or experience and acute/chronic weight loss practices; that is, all groups equally practised similar methods to acquire optimal body compositions (*P*=0.65). For the combined group 94% 'always' or 'sometimes' engaged in gradual dieting (Figure 3.1A), whilst 84% 'always' and 'sometimes' increased exercise levels (Figure 3.1C). Moreover, 64% 'always and 'sometimes' restricted foods (Figure 3.1D). In particular, CHO restrictions were 'always' and 'sometimes' practised by 70% of all athletes (Figure 3.1B). Water loading in the final pre-competitive period was reported by 73% in the combined group. Furthermore, 44% of all athletes 'regularly' used salt manipulation, with 60% of Figure novice athletes 'always' or 'sometimes' using this method prior to competition (Figure 3.1E). For the combined group skipped meals (86%), fasting (92%) and laxatives (91%) were 'almost never' or 'never used' (Figure 3.2). Overall, use of sauna (Figure 3.2H), sweatsuits (Figure 3.2A), and hot baths (Figure 3.2G) were not frequently used by all FP athletes.

The three most influential individuals on dieting and weight loss across all groups were the coach, another physique athlete and partners (Table 3.3). While the coach had the greatest influence across combined groups with 89% of all athletes reporting "quite" and "very influential", a high prevalence reported that parents (60%), professional practitioners (82%) and nutritionists (52%) provide 'no' or 'little' influence on practices.

Table 3.3: *Frequency analysis of the persons who are influential on the dieting practices and weight loss of female physique athletes (n=158) stratified by division and experience level.*

	Not influential %					A little influential %					Unsure %					Quite influential %					Very influential %				
Persons	**Fit Nov**	**Fit Exp**	**Fig Nov**	**Fig Exp**	**C**	**Fit Nov**	**Fit Exp**	**Fig Nov**	**Fig Exp**	**C**	**Fit Nov**	**Fit Exp**	**Fig Nov**	**Fig Exp**	**C**	**Fit Nov**	**Fit Exp**	**Fig Nov**	**Fig Exp**	**C**	**Fit Nov**	**Fit Exp**	**Fig Nov**	**Fig Exp**	**C**
Coach	8	15	0	4	9	0	4	0	0	1	0	2	5	0	1	21	21	16	17	20	71	59	79	79	69
Doctor	77	83	93	83	82	11	10	0	8	9	7	6	5	8	6	2	0	0	0	1	2	3	0	0	2
Internet	31	30	42	25	31	13	30	11	21	20	8	4	5	13	7	29	25	21	38	28	19	11	21	4	15
Another athlete	13	11	11	4	11	13	13	11	13	13	2	2	16	0	3	45	45	37	46	44	27	28	26	38	29
Friends	39	40	68	33	42	29	26	16	29	27	5	6	0	4	4	18	23	0	21	18	10	6	16	13	10
Partner	26	23	47	17	26	13	25	0	17	16	7	9	0	4	6	21	30	16	25	24	34	13	37	38	28
Parents	65	57	68	46	60	13	19	16	25	17	2	4	0	4	3	16	15	11	17	15	5	6	5	8	6
Training partner	37	45	53	33	41	16	21	11	25	18	8	8	0	0	6	26	19	26	21	23	13	8	0	21	12
Nutritionist/dietitian	46	45	84	58	52	13	6	0	8	8	10	11	0	0	8	13	19	0	17	14	18	19	16	17	18

Fit Nov= Fitness novice athletes, Fit Exp = Fitness experienced athletes, Fig Nov = Figure novice athletes, Fig Exp = Figure experienced athletes and C= Combined female physique athletes.

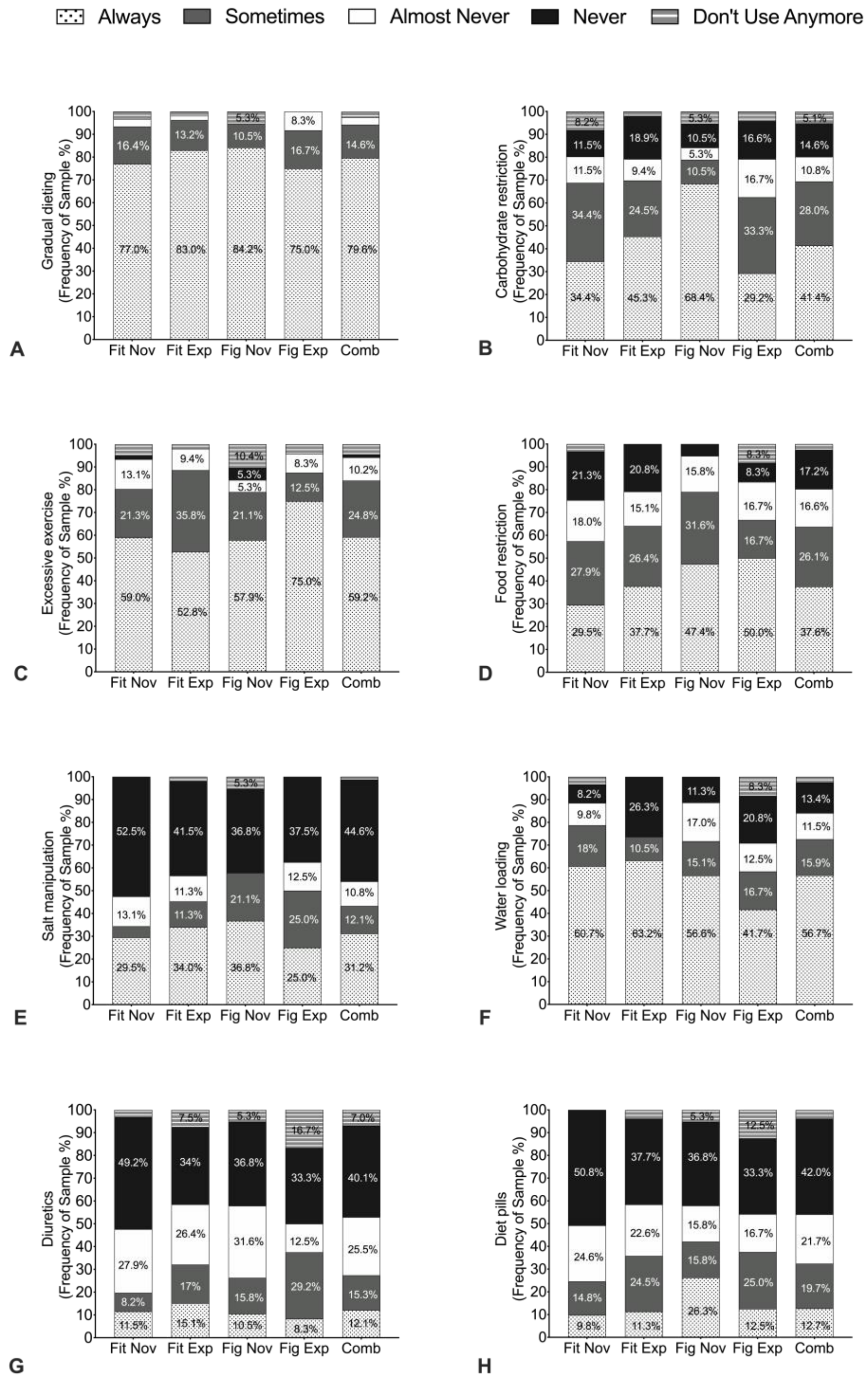

Figure 3.1*—Frequency analysis of weight loss methods. A = Gradual dieting B = Carbohydrate restrictions; C = Increasing exercise; D = Food restrictions; E = Salt manipulations, F = Water loading; G = Diuretics and H = Diet pills. Fit Nov = Fitness novice athletes, Fit Exp = Fitness experienced athletes, Fig Nov = Figure novice athletes, Fig Exp = Figure experienced athletes and Comb = Combined female physique athletes (Redrawn from Alwan et al., 2022).*

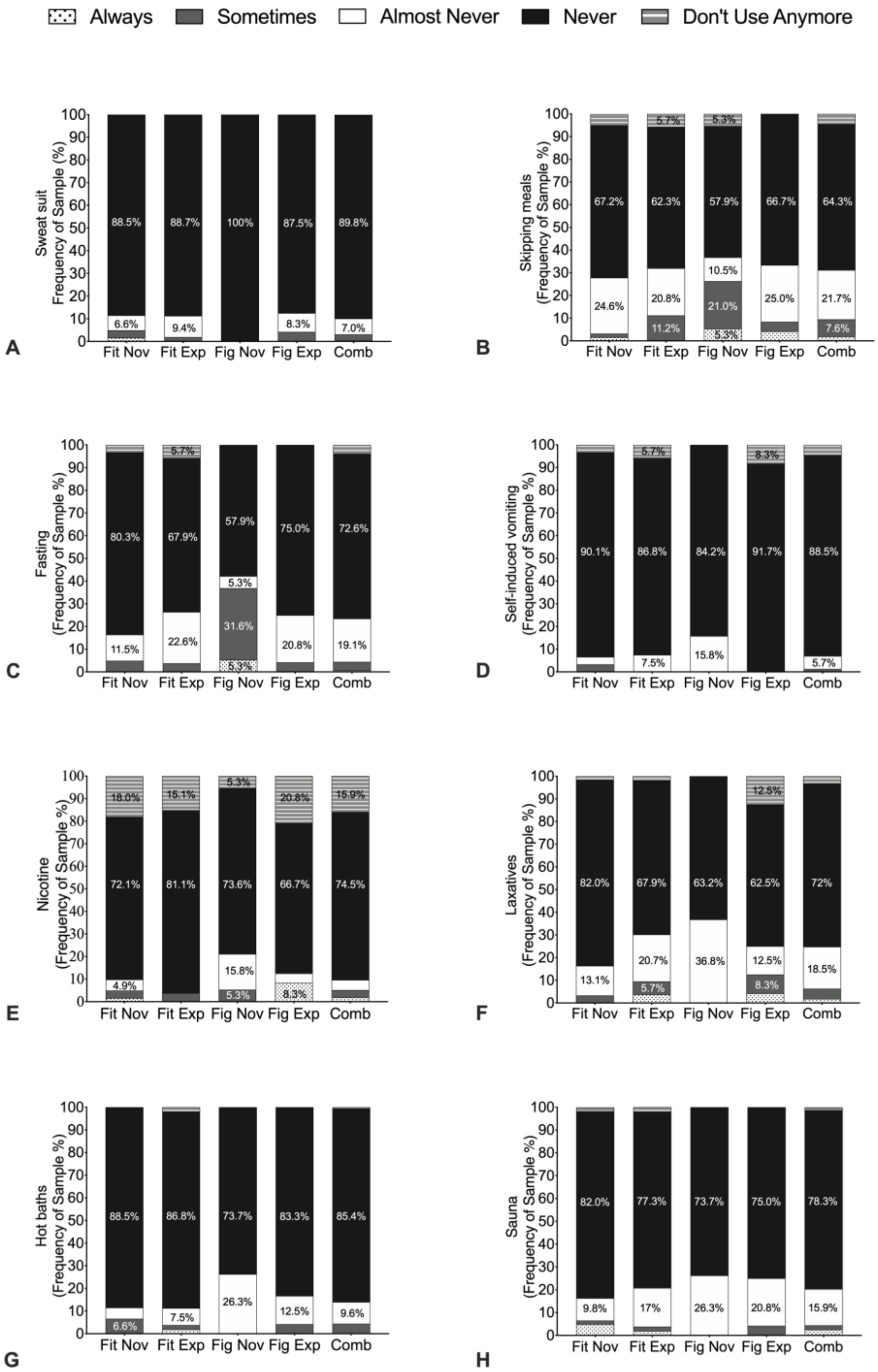

Figure 3.2*— Frequency analysis of weight loss methods. A = Sweatsuits; B = Skipping meals; C = Fasting; D = Self-induced vomiting; E = Nicotine; F = Laxatives; G = Hot baths; and H = Sauna. Carbohydrate and fat blockers and Enema were not illustrated here due being used less than 9 % by combined groups. Fit Nov = Fitness novice athletes, Fit Exp = Fitness experienced athletes, Fig Nov = Figure novice athletes, Fig Exp = Figure experienced athletes and Comb = Combined female physique athletes (Redrawn from Alwan et al., 2022).*

3.3.4 Disordered eating symptoms

In the present study 37.0% (*n*=56) of participants indicated a score ≥ 20 cut-off value and were therefore classified as having DE symptoms and at risk of developing an ED. There was no difference in the total EAT-26 score between novice and experienced athletes (19.2±12.1 *vs.* 17.1±13.9; P>0.05). Similarly, there was no difference in the total EAT-26 score between Fitness and Figure athletes (18.8±13.9 *vs.* 16.5±10.2; P>0.05). Oral control and dieting sub-scale scores from the EAT-26 test showed no differences between division or experience (P>0.05). Regarding the bulimia and food preoccupation score, there was a main effect for division where Figure athletes scored greater than Fitness athletes (3.8±3.7 *vs.* 4.7±3.7; P=0.01) but not for experience, and no interaction was found between division and experience.

3.3.5 Pathogenic weight control methods

For the combined group, 42.4% used two out of three PWCM, while 13.3% used all methods to manage their weight. Laxatives, diet pills and diuretics use were the most popular method to manage weight amongst all FP athletes (Figure 3.3C) with a large percentage of Fitness novice (77.1%), Fitness experienced (76.9%), Figure novice (77.0%) and Figure experienced (80.0%) athletes reporting its use once a month or more. Likewise, binge eating occurred once a month or more for 63.3% of all FP athletes. Of those, 14.8% of Fitness novice, 3.8% Fitness experienced, 35.0% of Figure novice and 0.0% Figure experienced athletes indicated binge eating once a week or more (Figure 3.3A). Self-induced vomiting (Figure 3.3B) occurred once a month or more in 21.3%, 26.9%, 15.0% and 20.0% of Fitness novice, Fitness experienced, Figure novice and Figure experienced athletes, respectively.

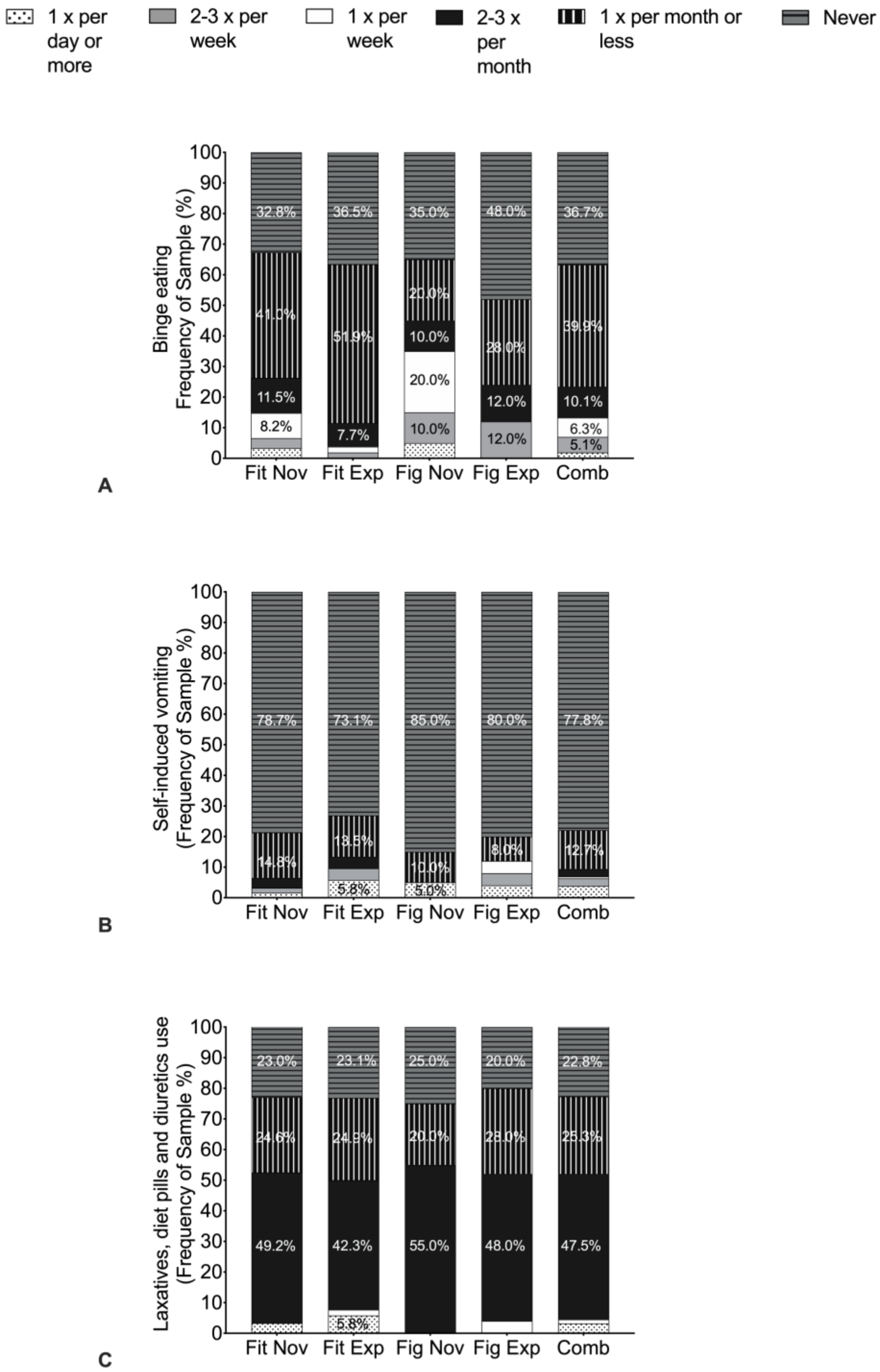

Figure 3.3*—Frequency analysis of pathogenic weight control methods used by physique athletes from the Eating Attitude Test-26 questionnaire. A = Binge Eating; B = Self-induced vomiting; C = Laxatives, diet pills and diuretics (water pills). Fit Nov = Fitness novice athletes, Fit Exp = Fitness experienced athletes, Fig Nov = Figure novice athletes, Fig Exp = Figure experienced athletes and Comb = Combined female physique athletes (Redrawn from Alwan et al., 2022).*

3.4 Discussion

This study provides data that asesses the weight loss history and frequency of practices in FP athletes alongside influential sources of dieting and DE symptoms. The results show that irrespective of division or experience level, FP athletes use gradual dieting, food restriction and excessive exercise and acute body water manipulation weight loss practices in pre-competition which provides additional knowledge on dieting procedures among this group. Coaches and other athletes were identified as the key influencers of dieting and weight loss practices. Moreover, 37.0% of all FP athletes were considered at risk of developing an ED (≥ 20 cut-off value in EAT-26 questionnaire. Lastly, almost half of the athletes used two PWCMs with over a third of Figure novice athletes reporting binge eating once a week or more.

In the present study, a number of athletes reported regaining significant body weight, with Figure athletes reporting the greatest relative weight regain (5.5%) in the 7-days after competition compared to Fitness athletes (4.1%). Interestingly though, the greatest weight individual regain was reported by a Fitness novice athlete, who increased BM by 15.9% (8.5 kg) in the first 7-days post-competition indicating that individual variability within groups was apparent. Although speculative, the greater relative weight regain in Figure athletes may be due to the higher frequency of binge eating self-reported by Figure athletes (47%) compared to the Fitness athletes (18.6%) and the greater bulimia and food preoccupation score in Figure athletes compared to Fitness athletes (Andersen et al., 1995; Lowe et al., 2006). Our findings confirm previous observations in FP athletes (Trexler et al., 2017; Longstrom, et al., 2020), which show similar rapid changes in BM post-competition. Rapid changes to post-competition BM could be explained by rebound hyperphagia, which often occurs in response to chronic and intensive periods of energy restriction (Dulloo et al., 2015; Wang et al., 2001) and may increase the risk for obesity and cardiometabolic diseases in later life (Miles-Chan & Isacco, 2020).

In pre-competition, FP athletes implement gradual dieting, food restrictions, excessive exercise and water loading. In attempting to lose weight, engaging in restrictive eating and excessive exercise could potentially affect metabolic (Trexler et al., 2017) and endocrine health such as menstrual dysfunction (Halliday et al., 2016) thus increasing the risk of RED-S (Mathisen et al., 2019). Our findings also confirm and extend recent work from Chappell & Simper (2018) showing that a high proportion of FP athletes will ‘always’ or ‘sometimes’ use CHO, salt, and fluid manipulation in the final 7-days pre-competition. However, it is worth noting that Chappell & Simper (2018) did not separate athletes into respective divisions, which could be important because of the different body composition requirements (Alwan et al., 2019). Water loading (*i.e.*, consuming approximately ~10 litres of water per day for 3-5 days), followed by reduced water intake each day leading into the competition with complete fluid restriction over the 10-24 hours before the performance on the stage (Mitchell et al., 2017), was used by >70% of the FP athletes with no significant difference in its use between divisions in this study. Despite the high prevalence, water loading in isolation has been suggested to be a safe and effective method to increase urine production for a maximal fluid driven weight loss in combat sports (Reale et al., 2018). However, this practice when combined with diuretics and electrolyte manipulation presents additional dangers including hyponatremia, which has resulted in a number of fatalities (Adrogué &

Madias, 2000b; Garigan & Ristedt, 1999) and is not a recommended method to regulate weight (Mountjoy et al., 2014). A unique finding of our study was the higher prevalence of diet pills and diuretics (32 and 27%, respectively) to lose body water compared to previous work, which did not report these methods (Andersen et al., 1998). A possible explanation for the disparity between studies could be due to our larger sample size (*n*=26 versus *n*=158, respectively) and the addition of new divisions in recent years which require specific body composition requirements (Alwan et al., 2019).

FP athletes reported coaches and other physique athletes to be the greatest influences on their dieting and weight loss efforts, whilst medical doctors and nutritionists were not seen as influential. This agrees with other studies on weight-sensitive sports (Chappell et al., 2018; Artioli et al., 2010; Whitehead et al., 2020). For example, Chappell et al., (2018) reported that 14 out of 16 FP athletes used a coach for guidance with training, dietary practices and feedback on their physique. A possible explanation for why coaches appear to be highly influential is that many former athletes become coaches toward the end of their careers (Mitchell et al., 2017). This might result in systemic cultural attitudes toward aggressive weight loss practices being preserved within physique sports, although, this has only been shown in male bodybuilding (Mitchell et al., 2017 and Lenzi et al., 2021) and therefore warrants further investigation in FP athletes. If this is the case, collectively these data highlight the need for coaches to be adequately educated regarding safe and effective methods of weight management in an attempt to improve the health and well-being of athletes. Bodybuilding and fitness organisations should consider providing continuing professional development courses from suitable professionals for members and encourage the support of multidisciplinary teams (*i.e.*, registered sports psychologists and sports nutritionists/dietitians). In addition, online resources (41%) were ‘quite’ and ‘very’ influential methods of information for athletes. Seeking information from internet resources has previously been shown to significantly cause unintended body dissatisfaction (Tiggemann & Zaccardo, 2015) and correlated with DE (Moorman et al., 2020) and therefore highlights the importance of educating athletes correctly, as unregulated online advice could be detrimental to training, performance and health.

Our data show that 37.0% of the combined group scored greater than the cut-off value for the EAT-26 questionnaire. The proportion of FP athletes considered at risk of ED in this study strongly agrees with Whitehead et al., (2020) (using a comparable EDI questionnaire) which showed that 50% of Australian FP athletes were identified with DE (Whitehead et al., 2020) and Money-Taylor et al., (2021) (using a similar screening tool to that of the present study) which showed that 57% of international FP athletes were identified with DE symptoms. Furthermore, the Figure novice athletes scoring greater than the cut-off value (>20) suggests Figure novice athletes are at greater risk for ED than Figure experienced, and Fitness groups. Due to the specific demands of the Figure division (*i.e.*, lower FM and higher FFM than the Fitness division), novice athletes beginning Figure competitions may be exposed to body composition requirements that are more challenging to achieve (Aspridis et al., 2014). It is also possible that women may be susceptible or already exhibit DE symptoms, as they enter physique sports, in hopes of alleviating these symptoms. As such, it is speculative whether long-term engagement in the sport provides a protective effect from ED risks in FP athletes (Mitchell et al., 2017). Although, EAT-26 questionnaire has been validated in other athletic groups, further work to validate it in this specific population is necessary.

For pathogenic eating and weight control methods, over 40% percent of all athletes engaged with two of the three methods to manage weight, whilst 13% of athletes reported engaging with all three. These percentages are similar to those reported previously on FP athletes (Walberg & Johnston, 1991; Whitehead et al., 2020). FP athletes commonly experience pressures to remain extremely lean (Kong & Harris, 2015), which can lead to cycling between restrictive eating behaviours and excessive exercise, to repeated binge eating episodes (Mathisen & Sundgot-Borgen, 2019). This is of particular interest considering FP athletes repeat weight cycling episodes and therefore may experience higher rates of obesity and cardiometabolic disease later in life (Miles-Chan & Isacco, 2020).

A recent observation suggests that athletes who have an underlying predisposition to developing an ED are more attracted to participate in physique sports (Mitchell et al., 2017). For example, key psychopathological traits underpinning the development of DE are often seen in physique sports (Goldfield et al., 1998; Hurst et al., 2000). Our data showed high levels of food restraint amongst all participants (approximately 40% reported 'always' food restricting), which is in agreement with a recent report (Mathisen & Sundgot-Borgen, 2019) which revealed higher eating restraint in FP athletes compared to healthy controls before, during and post dieting. Moreover, Mathisen & Sundgot-Borgen (2019) reported that 9 (28%) and 2 (6%) out of 33 Scandinavian FP athletes had currently or have previously been diagnosed with an ED diagnosed by health personnel. These findings have serious implications for FP athletes and those managing these athletes such as coaches with respect to detecting DE early. Thus, education programmes should encourage organisations, coaches and physique athletes themselves to seek support from multidisciplinary professionals on the identification, prevention and management of DE/ED, and this should apply to all female athletes adhering to the extreme modern body ideal emphasising a lean and muscular aesthetic look.

A limitation of the present study is that athletes gave self-reported responses and therefore may have over or under-reported their weight history and weight loss/gain based on records/memory (Sundgot-Borgen, 1993). Furthermore, the participant responses could be biased or influenced by personal subjective perceptions and beliefs of their own weight loss or weight gain and eating behaviours. Although EAT-26 has been widely used in physique and bodybuilding populations (Goldfield et al., 1998; Pickett et al., 2005), it has only been validated in other athletic groups such as cross-country skiing, track and field and team sports (Pope et al., 2015). As such, EAT-26 questionnaire contains components which could be interpretated as pathological eating behaviours (*e.g., 'I engage in dieting behaviour'* and *'Aware of the calorie content of foods that I eat'*), which could well be normal behaviours which are required to compete in physique sports, rather than being indicative of DE per se. As such, distinguishing between true pathological and non-pathological behaviours eating behaviours should be carefully considered when interpreting the DE symptoms results. It should also be considered that weight loss values were made relative to their off-season time-point, as such this will be different between people and also the time-point of the pre-competition period. Finally, although the overall sample size in our study (n= 158) was substantially larger than previous cross-sectional studies in this population (n=26 (Andersen et al., 1998); n=14 (Chappell et al., 2019), the small number of participants competing in Women's Fitness and Physique divisions (described in literature review; section 2.3) meant that it was not possible to analyse the differences between every division. However, it must be acknowledged that athletes competing in Women's Fitness, Wellness and Physique divisions are more likely to engage with prohibited substances given the expectations to achieve less FM and greater LBM (Gentil et al., 2017; Grogan et al., 2004; Thiblin et al., 2009).

In an attempt to further understand the weight management of FP athletes and potential risks of acute and chronic health outcomes, future work should i) validate EAT-26 questionnaire in physique athletes, ii) assess dietary intake using weighed food inventory and food diaries, alongside training practices (modality, training volume and loads) during the pre-competition phase and iii) collect blood samples and other measurements for analysis of markers relating to metabolic, renal and endocrine health (especially on changes in competition week). Using qualitative techniques to characterise the physical and psychological health implications when participating in physique sports (*i.e.,* lived experiences) could also further understanding.

3.5 Conclusion

Irrespective of division or experience, FP athletes used a combination of chronic and acute weight loss practices including gradual dieting, food restrictions, excessive exercise and water loading in pre-competition. Figure novice athletes reported most weight loss pre-competition, alongside significant increases in weight gain post-competition, indicating patterns of weight cycling. Coaches and other athletes had most influence on athletes' practices. Finally, 37% of FP athletes were at risk of developing ED with 42% using two PWCM throughout the season.

Therefore, we encourage FP athletes and coaches to utilise appropriate expertise (*e.g.,* registered nutritionists and psychologists) when preparing for competition. This might reduce the risks associated with severe weight loss practices evident in this population.

[redacted] 4. Pre-competition energy intake, training load and well-being in female physique athletes: Observational evidence of self-reported nutritional and training load periodisation

4.1 Introduction

Achieving the ideal body composition for competition is pivotal for FP athletes as it directly impacts competition judging (Chapter 2). The pre-competition phase is a particularly demanding period of the competitive season, regardless of division or experience in the sport, can be characterised by gradual dieting and food restrictions paired with excessive exercise (Study 1, Chapter 3). In male bodybuilders, the pre-competition phase reveals high resistance and aerobic training volumes (TV) (Hackett et al., 2013), reductions in TEI and alterations in macronutrient intake (Mitchell et al., 2018). Practising such nutritional and training strategies leads to energy restriction and may cause chronic LEA and symptoms of RED-S (Fagerberg, 2018) including compromised psychological indices such as well-being and mood states. Although similar practices and outcomes may apply to FP athletes (Tinsley et al., 2019b), the specifics of how (and if) FP athletes modify nutritional and training practices in the pre-competition phase, remains unclear in the current literature. It is important to assess specific practices in FP athletes, as without understanding their current approaches, practitioners and researchers will not be able to effectively understand, intervene or support these athletes.

Several studies have shown that FP athletes reduce their EI (Halliday et al., 2016; Mathisen et al., 2019; Tinsley et al., 2019a) and CHO intakes (Halliday et al., 2016; Rohrig et al., 2017) whilst maintaining their protein intake prior to competition (Mathisen et al., 2019; Petrizzo et al., 2017; Tinsley et al., 2019b). There are, however, methodological issues with previous studies which limit the ability to clearly identify the dietary manipulations. For example, submission of diet plans by coaches (instead of athletes recording their intakes) (Mathisen et al., 2019; Tinsley et al., 2019b), omission of the data collection period and assessment tool (Chappell et al., 2018; Hulmi et al., 2017) and use of a single method of assessing EI (Longstrom et al., 2020; Trexler et al., 2017). The known limitations of these methods (*e.g.*, underreporting (Capling et al., 2017b) make it difficult to understand whether current nutritional practices of FP athletes are consistent with recommendations for athletes undergoing energy restriction (Hector & Phillips, 2018). Moreover, it is unknown whether the distribution of CHO and protein intakes practised by FP athletes during training days adheres to the current guidelines relating to key time periods of nutrient intake (Slater and Phillips 2011). For example, to maximise muscle protein synthesis during periods of negative energy balance (Areta et al., 2013), regular protein ingestion combined with resistance training may assist in the maintenance of FFM.

In contrast to male counterparts, the current understanding of the training requirements of natural FP athletes is limited (Hackett et al., 2013; Mitchell et al., 2018). Documentation of training practices in FP athletes is mostly reliant on metabolic equivalent data (Halliday et al., 2016; Petrizzo et al., 2017; Hulmi et al., 2016), which provides estimates of EEE (Ainsworth et al., 2000), but does not detail specific training practices. It is therefore unclear if training variables are manipulated by FP athletes who are actively engaging in weight loss for competition (Helms et al., 2015). Gaining a descriptive account of current practices could help to formulate the training modalities, durations, loading strategies and recovery protocols for this population.

During the pre-competition phase FP athletes suffer from negative psychological well-being and moods states (including increased depression and decreased vigour) (Hulmi et al., 2017; Rohrig et al., 2017; Rossow et al., 2013). This may predominantly be due to prolonged periods of dietary restraint causing a strain on mental health. As such, this information allows researchers to assess whether interventions need to take place to improve mental health of the athlete. Two studies have measured mood states in FP athletes; however, these studies have been limited to a case report (Rohrig et al., 2017) or measured and compared changes in mood states across different competitive phases (Hulmi et al., 2017). Additionally, well-being markers have not been objectively assessed in this population. An assessment of well-being and mood states (*e.g.*, recovery, fatigue and motivation) will allow practitioners to better manage overall psychological health, performance, injury prevention and recovery of FP athletes (Mathisen & Sundgot-Borgen, 2019; Rohrig et al., 2017). Accordingly, the purpose of this study was therefore to quantify pre-competition EI, training load (TL) and well-being in FP athletes.

4.2 Materials and methods

4.2.1 Participants

Nine FP athletes (mean ± SD: age 26 ± 2 years, BM 60.8 ± 8.5 kg, height 165.8 ± 8.7 cm) with 2 ± 2.5 years of competitive experience from Bikini fitness (n=8) and Figure (n=1) divisions were recruited for the study via social media advertisement (April 2018-April 2019) and snowball sampling, whereby athletes were invited to pass recruitment material to other prospective participants (Naderifar et al., 2017). These divisions are previously presented in the review by Alwan et al., (2019) and athletes were not required to be a particular weight class. All athletes competed in WADA drug testing organisations. Following a written and verbal explanation of the study details, participants gave written informed consent to participate. The study received ethical approval from the University (18/SLM/009). All athletes had coaches (ranging from qualified personal trainers, competitive bodybuilders with extensive coaching experience, and strength and conditioning coaches) who guided them on the nutrition and training approaches at the time of the study.

4.2.2 Design

The study adopted a Public and Patient Involvement (PPI) trial (Cockcroft, 2020) during the development of the study design. This involved including athletes (not involved in the present study) in the early planning phase which enabled researchers to navigate appropriate research methods, and increase value, relevance and accountability to study participants (Cockcroft, 2020; Davies et al., 2017) (appendix 9.1, Chapter 9). For example, athletes were asked how many weeks they would use to prepare for competition, when they were likely to modify their training and dietary practices, the number of days they would voluntarily log dietary intake and training information, and which methods they would prefer using (*e.g.*, focus group, interviews and food diary) if they were taking part in a research project.

A private link to an online diary was distributed to participants using a web-based platform (Google Forms, Google, CA, USA), in which all nutrition, training and well-being data was logged by participants for the same three days at each time-point (-12WK, -4WK and -1WK) while mood state was only logged on the third day of each time-point (April-December 2018-2019) (See Figure 4.1). All participants completed a familiarisation trial of the online diary. Authors made no attempt to influence any of the dietary intakes, resistance training or preparation during the observation phase. Participants were instructed to complete the online diary individually to avoid potential influences from peers. Participants were instructed to complete the online diary by the end of each day (23.59 hrs) (Borresen & Ian Lambert, 2009; Phibbs et al., 2017) for all three days at each time-point. In the diary, participants were asked to record their fasted BM (upon waking) and complete a combined weighed food diary (food diary and weighed food inventories) over three non-consecutive training days (two weekdays and one weekend day which represented an upper-, lower- and whole-body session). A three-day monitoring period, an accepted method used in athletic studies (Larson-Meyer et al., 2018) was decided because of the minimal participant burden (Capling et al., 2017b) and physique athletes repetitious and monotonous dietary and training practices in the pre-competition phase (Kleiner et al., 1994; Sandoval & Heyward, 1991).

Training practices (timing, durations, modality, and internal aerobic and resistance exercise, and internal TL and resistance training volume and index) were recorded into the diary for the same three non-consecutive training days. A 24-hour dietary recall was adopted at the end of each three-day period in addition to the food diary (Figure 4.1). This recall, conducted on day 4, aimed to capture dietary intakes from day 3. The advantage of including a 24-hour dietary recall is that the outcome is not influenced by athletes' awareness and subsequently a modified and desirable intake as observed with food diaries in isolation (Wardenaar et al., 2015). A 24-hour dietary recall combined with food diary has previously been shown to be a valid technique to capture dietary intake in free-living conditions (Briggs et al., 2015).

The psychometric measurements included the Brunel Mood Scale (BRUMS) questionnaire (Terry et al., 1999) and Daily Well-being Score (McLean et al., 2010). Athletes were instructed to inform the principal investigator, if they were uncertain about any words in the questionnaire.

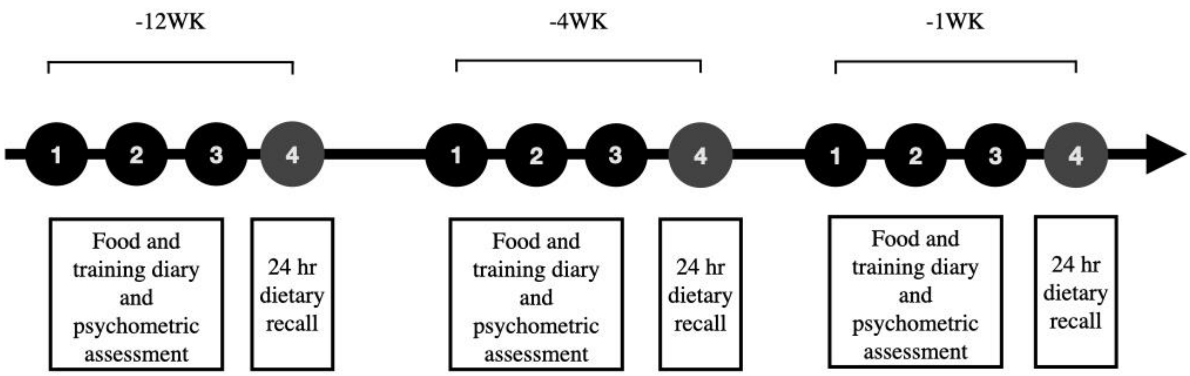

Figure 4.1 *—Illustration of the study protocol. WK = Weeks, numbers in black circles means days. Brunel Mood Scale questionnaire was completed on the third day of recording due to the 7-day data capture period, whilst Daily Well-being Score was completed every day in the study period.*

4.2.3 Self-reported body mass

Participants were instructed to measure fasted BM upon waking using commercial scales provided by the principal researcher (unbranded, Amazon, UK), which was recorded into the online diary for each day at -12WK, -4WK and -1WK. To standardise BM measurements, participants were encouraged to measure their BM the same time of the day, after voiding and wearing the same minimal clothing. To estimate whether athletes were in an energy deficit, a resting energy expenditure equation based on BM (ten Haaf & Weijs, 2014) was calculated. The value was then subtracted from their self-reported EI in absolute terms. This equation was selected based on previous work (Tinsley et al., 2019) which found it suitable when working with FP athletes.

4.2.4 Self-reported energy intake and macronutrients

The 3-day weighed food diary (Larson-Meyer et al., 2018) required participants to weigh and record all foods and beverages consumed using commercial weighing food scales with information of food/beverage item, weight, product brand, time of consumption and cooking preparation (raw or cooked) and any complementary additions (oils, sauces or spices). Moreover, participants were instructed to record supplement information daily. Additionally, a 24-hour diary recall was adopted at the end of each three day period to recall day three of the weighed food diary entry and captured any missing or additional information from day one and two of weighed food diary entries (Briggs et al., 2015). To ensure inter-reliability of EI and macronutrient intake data input, two Sport and Exercise Nutrition Registered (SENr) practitioners (the lead researcher and another independent practitioner) individually and at random analysed one day of a weighed food diary day for a subgroup of athletes (n=5). CV% between the two practitioners for total EI, CHO, proteins and fats were 2.0, 3.3, 4.3 and 4.6%, respectively and are presented as Bland-Altman plots (appendix 9.2, Chapter 9); (Bland-Altman bias = -37 Kcal (95% CI: -133.8, 59.8 kcal), 6.0 g (95% CI: -4.4, 16.5 g), -4.4 g (95% CI: -23.0, 14.2 g) and -9.3 g (95% CI: -37.0, 18.4 g) for EI, CHO, proteins and fats, respectively).

Macronutrient distribution was categorised into nine eating windows, as defined by participant's breakfast, morning snack, lunch, afternoon snack, dinner, evening snack, pre sleep, during training and post training. Mean EI, CHO, protein and fat content for each eating window for all time-points (*i.e.*, combined -12WK, -4WK and -1WK prior to competition) was determined. Food diary data (including supplements) was analysed using Nutritics software (version 26, Nutritics Ltd, Co. Dublin, Ireland). All analyses were carried out by a single researcher so that potential variation of the data input and interpretation was minimised (Deakin, 2000).

4.2.5 Self-reported training duration, load and volume

Aerobic and resistance training internal training load (TL) was quantified by participants' rating the intensity of their sessions using a 10-point rating of perceived exertion scale (RPE) (Siegl & Schultz, 1984). The RPE rating for each training session was then multiplied by the duration of exercise (RPE x session duration in minutes) to quantify an index of the TL, also referred to as the sRPE-TL (Foster et al., 1996). Daily sRPE-TL for both aerobic and resistance training sessions were summed for each time point to calculate accumulated sRPE-TL. The timing and the accumulated training duration for both aerobic and resistance training were also reported. Aerobic training was defined as exercise protocols that involved rhythm contractions of large muscle groups and could be maintained continuously (*i.e.,* cycling, walking/running, stepping exercise and elliptical-based activities) with reliance on cardiorespiratory systems (Caspersen et al., 1985; Leddy & Izzo, 2009). Resistance training was defined as exercise protocols where muscle exerted a force against body weight or external resistance repetitively using a wide range of training modalities designed to induce strength and hypertrophy stimuli (Caspersen et al., 1985; Singh et al., 2007).

Resistance TV was collected throughout each time-point using the volume load method (Haff, 2010) which is the multiplication of the number of sets, repetitions per set, and weights (kg) lifted by each participant in each session, and then summed for all exercises performed (Haff, 2010). This method has previously been used to quantify total resistance TL in resistance-trained populations (Mitchell et al., 2018). Using the allometric formula recommended by (Haff, 2010), allowed TV load index (independent of BM) to be calculated.

4.2.6 Perceived psychological well-being and mood states

On the third day of each time-point, participants were instructed to complete the BRUMS questionnaire (due to its weekly nature of measure). This 24-item questionnaire is composed of six subscales (anger, confusion, depression, fatigue, tension and vigour) and is used to describe mood states on a 0-4 Likert scale over the course of the previous seven days. The vigour–activity score is subtracted from the sum of all other subscale scores to determine the total mood-disturbance (TMD) (Rossow et al., 2013). The questionnaire is validated in athletes and has been used in weight-restricted sport research (Robinson 2015; Wilson et al., 2014). Furthermore, well-being was assessed via Daily Well-being Score (McLean et al., 2010) each day of the monitoring period across time-points. Within the well-being assessment, daily fatigue, sleep quality, general muscle soreness, stress level and mood were rated by participations on a 1-5 Likert scale. The sum of all five scores was utilised to characterise overall well-being with < 7 indicative of low, 8-16 moderate and > 17 high scores (McLean et al., 2010).

4.2.7 Statistical analysis

Statistical analyses were performed using SPSS (version 24, SPSS, Chicago, IL). Normal distribution of continuous data was assessed with Normal Q-Q plots and

Shapiro Wilk Test. For normally distributed data, statistical comparisons between time-points were performed using a one-way within-subjects analysis of variance (ANOVA). Where significant main effects were present, Bonferroni post hoc analysis was performed. For EI and macronutrient distributions, a two-way (mealtimes x time-points) ANOVA with repeated measures was performed. Mauchly's test analysed the sphericity assumption and the Greenhouse-Geiser adjustment was used, when required. Where data was not normally distributed, Kruskal-Wallis H tests were used. To determine the difference in BM change between -12WK and -4WK, and -4WK and -1WK, a paired samples *t*-test was performed. Data are represented as means and standard deviations (SD). Ninety-five percent confidence intervals (95% CI) for the differences are presented on significant values. Meaningful effect sizes (ES) were calculated as the difference between the means divided by the pooled standard deviation with the following criteria for ES used to explain practical significance of the results: trivial: <0.2, small: 0.21-0.6, moderate: 0.61-1.2, large: 1.21-1.99, and very large: ≥ 2.0 (Hopkins, 2006). ES were calculated and reported for body weight, EI, macronutrients, aerobic and resistance TL, resistance TV, mood and well-being followed by 95% CI for each of the ES values. Statistical significance level was accepted at $P < 0.05$. In the results, *absolute* refers to the absolute intake of CHO, fats or proteins, while *relative* refers to when the absolute values have been normalised for BM (*i.e.,* $g.kg^{-1}$).

4.3 Results

4.3.1 Self-reported body mass

Absolute BM (Figure 4.1A) was significantly different between time points ($F_{1,10}$=16.56, P<0.01). At -12WK (60.9 ± 8.1 kg) the FP athletes were heavier than at -4WK (57.5 ± 8.9 kg; 95% CI=0.55 to 6.16 kg; P=0.02; ES=0.38, 95% CI=-0.56 to 1.31) and -1 week (55.6 ± 8.9 kg; 95% CI=1.64 to 8.87 kg; P=0.01; ES=0.59, 95% CI= -0.36 to 1.53). BM was also significantly different between -4WK and -1WK (95% CI=0.35 to 3.44 kg; P=0.02; ES=0.20, 95% CI= -0.72 to 1.13). There was no difference between BM change -12WK to -4WK (Δ 3.4 ± 2.8 kg) and BM change -4WK and 1WK (Δ1.9 ± 1.6 kg; t(8)= 1.59, P=0.15) (Figure 4.1B). Using a resting energy expenditure equation based on BM (ten Haaf & Weijs, 2014), it was estimated that almost every athlete (n=8) experienced an energy deficit for eight weeks whilst six athletes experienced an energy deficit for 12 weeks with mean values of -515 ± 189 kcal.day^{-1}, -903 ±139 kcal.day^{-1} and -458 ± 253 kcal.day^{-1} at -12, -4 and -1WK, respectively.

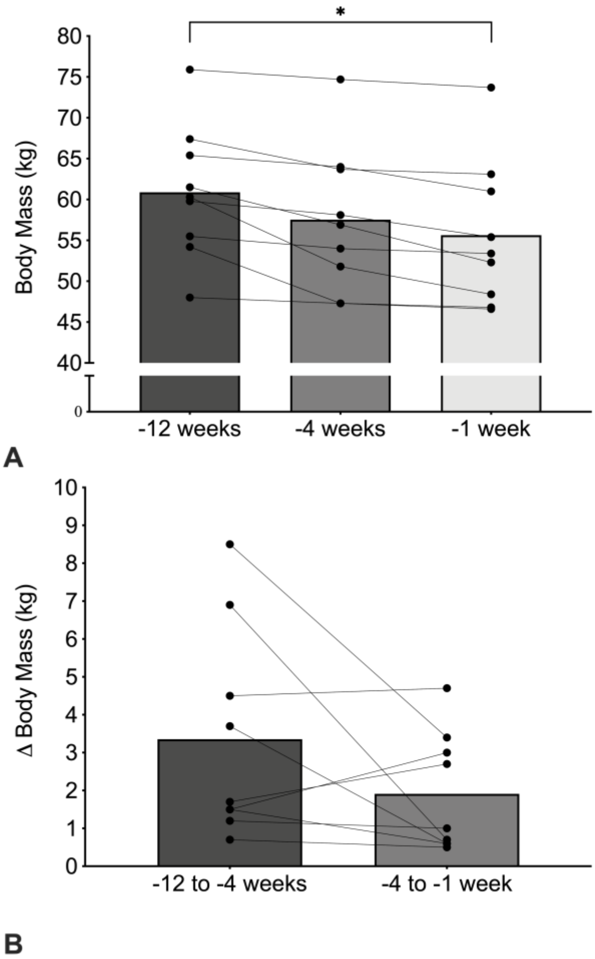

*__Figure 4.2__— Absolute and change in body mass over 3-day testing period across -12 weeks, -4 weeks and -1 week pre-competition. Figure 4.2A: Body mass in absolute terms, Figure 4.2B: Change in body mass are between -12 weeks and 4 weeks and between -4 weeks and -1 week. For A: *denotes significant difference between -12 weeks and -1 week , P<0.05, and for B: No difference between BM change of -12 to -4 weeks and BM change of -4 to -1 weeks. Black circles represent individual athletes. Lines represent the changes across time between each athlete.*

4.3.2 Self-reported energy and macronutrient intake

Absolute mean EI (Figure 4.3A) was significantly different between time points ($F_{2, 16}$=6.06, P=0.01). At -12WK (1738.1± 235.7 kcal.day^{-1}) participants consumed greater energy than at -1WK (1379.3±285.1 kcal.day^{-1}; 95% CI=36 to 682 kcal.day^{-1}; P=0.03; ES=1.31, 95%CI= 0.29 to 2.32). In contrast, no difference in EI was evident between -4WK and -12WK (P=0.99; ES=0.37, 95% CI= -0.56 to 1.30) or -1WK (P=0.08; ES=0.72, 95%CI= -0.24 to 1.67). In relative terms ($F_{2, 16}$=2.83, P=0.09) the FP athletes consumed similar energy (Figure 4.3B) at -4WK (P= 1.00; ES= 0.02, 95% CI= -0.91 to 0.94) and -1WK (P=0.14; ES= 0.74, 95% CI= -0.22 to 1.69) when compared to -12WK. Similarly, there was no difference in relative EI between -4WK and -1WK (P=0.20; ES=0.49, 95% CI= -0.45 to 1.42).

Absolute ($F_{2,16}$=2.65, P=0.10) mean CHO intake (Figure 4.3C) was similar between -12WK and -4WK (P=1.00; ES=0.21, 95% CI= -0.72 to 1.13), -12WK and -1WK (P=0.90; ES=0.70, 95% CI= -0.25 to 1.65), and between -4WK and -1WK (P= 0.58; ES=0.49, 95% CI= -0.45 to 1.42). When expressed in relative terms ($F_{2,16}$ =1.73, P=0.21), no differences were evident between -12WK and -4WK (P=1.00; ES=-0.02, 95% CI= -0.95 to 0.90), or between -12WK and -1WK (P=0.25; ES=0.54, 95%CI= -0.40 to 1.48). Moreover, there was no difference between -4WK and -1WK (P=0.62; ES=0.45, 95%CI= -0.49 to 1.38; Figure 4.3D).

Absolute ($F_{2,16}$=6.72, P=0.01) mean protein intake (Figure 4.3E) was different between -12WK (166.0 ± 14.4 $g.day^{-1}$) and -1WK (136.7 ± 29.5 $g.day^{-1}$; 95% CI=5 to 54 $g.day^{-1}$; P=0.02; ES=1.20, 95% CI= 0.20 to 2.2), however was similar between -12WK and -4WK (P=0.73; ES=0.40, 95% CI= -0.53 to 1.33) and between -4WK and -1WK (P=0.18; ES=0.72; 95% CI= -0.24 to 1.67). When expressed in relative terms ($F_{2,16}$=1.17, P=0.34), no difference was evident between -12WK and -4WK (P=1.00; ES=-0.21, 95% CI= -1.14 to 0.71) or -1WK (P=1.00; ES=0.30, 95% CI=-0.63 to 1.23). Similarly, there was no difference between -4WK and -1WK (P=0.57; ES=0.44, 95% CI= -0.50 to 1.37; Figure 4.3F).

Absolute ($F_{2, 16}$ =3.99, P=0.04) mean fat intake (Figure 4.3G) was different between -12WK (48.7 ± 14.5 $g.day^{-1}$) and -1WK (35.5 ± 17.85 $g.day^{-1}$, P=0.03; ES=0.77; 95% CI= -0.19 to 1.73) but was similar between -12WK and -4WK (36.6 ± 11.6 $g.day^{-1}$, P=0.06; ES=0.88; 95% CI= -0.09 to 1.84). In addition, the participants consumed similar amounts of fat at -4WK as -1WK (P=0.8; ES=0.07, 95% CI= -0.86 to 0.99). When expressed in relative terms ($F_{2,16}$=2.52, P=0.11), no difference was evident between -12WK and -4WK (P=0.28, ES=0.64, 95% CI= -0.30 to 1.59) or -1WK (P=0.20; ES=0.52, 95% CI= -0.42 to 1.46). Similarly, there was no difference in relative fat intake between -4WK and -1WK (P=1.00; ES=-0.02, 95% CI=-0.94 to 0.90; Figure 4.3H).

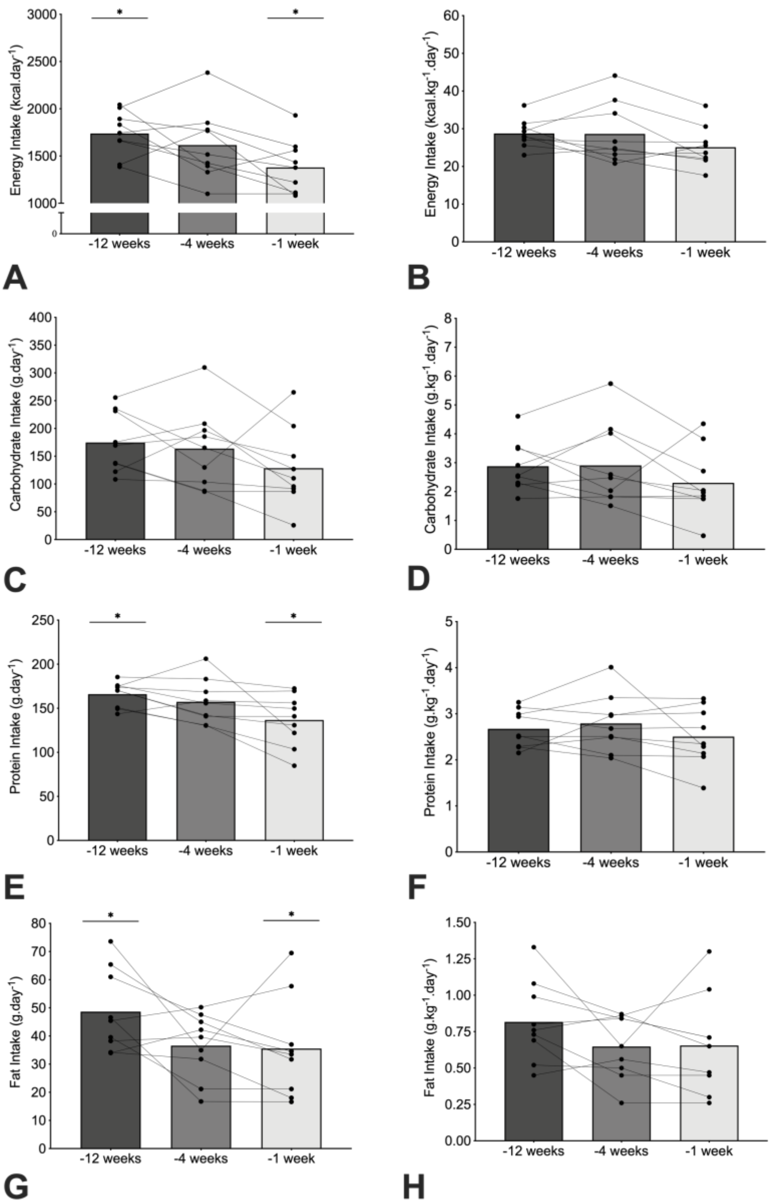

***Figure 4.3**— Daily energy and macronutrient intake expressed absolutely and relative to body mass over 3-day testing period across three time-points in pre-competition period. Figure 4.3A=absolute energy intake, Figure 4.3B=energy intake relative to body weight, Figure 4.3C = Absolute carbohydrate intake, Figure 4.3D=carbohydrate intake relative to body weight, Figure 4.3E=Absolute Protein intake, Figure 4.3F=Protein intake relative to body weight, Figure 4.3G=Absolute Fat intake, Figure 4.3H= Fat intake relative to body weight. *denotes significant difference between -12 weeks and -1 week time-point, P<0.05. Black circles represent individual athletes. Lines represent the changes across time between each athlete.*

4.3.3 Macronutrient distribution

There was a significant difference between -12WK (188.7 ± 142.6 kcal.day^{-1}and -1WK (152.5 ± 134.1 kcal.day^{-1}; 95% CI=1 to 71 kcal.day^{-1}, $F_{2,14}$ = 5.43, P=0.04) in EI per meal. EI was also significantly different across mealtime points ($F_{8,24}$=12.41, P<0.01). There was a significant difference (Table 4.1) in absolute EI between breakfast and the following mealtimes: evening snack (95% CI=121 to 366 kcal. meal^{-1}, P<0.01), pre-bed (95% CI=13 to 277 kcal. meal^{-1}, P=0.03) and during training (95% CI=180 to 335 kcal. meal^{-1}, P<0.01). Additionally, a significant difference in EI was evident between AM snack and dinner (95% CI=-257 to -25 kcal. meal^{-1}, P=0.02). EI at lunch was different compared to evening snack (95% CI=68 to 329 kcal.meal^{-1}, P<0.01) and during training (95% CI=58 to 367 kcal.meal^{-1}, P<0.01). EI was also different between dinner and evening snack (95% CI=134 to 378 kcal. meal^{-1}, P<0.01) and during training (95% CI=106 to 434 kcal. meal^{-1}, P<0.01). Differences were also between evening snack and post-training (95% CI=-326 to -3 kcal. meal^{-1}, P=0.04), and between during training and post-training (95% CI=7 to 350 kcal. meal^{-1}, P=0.04). No interaction between mealtimes and time-points were detected for EI.

There were no differences for time-point in CHO intake per meal (P=0.10). CHO intake was however significantly different across mealtime points ($F_{3, 26}$=7.18, P<0.01) (Table 4.1). There was a significant difference (Table 4.1) in absolute CHO intake between breakfast and evening snack (95% CI=7 to 48 g.day^{-1}, P=0.01) pre-bed (95% CI=3 to 43 g.day^{-1}, P=0.02) and during training (95% CI=9 to 52 g.day^{-1}, P=0.01). Additionally, a significant difference was reported between PM snack and during training (95% CI= 5 to 37 g.day^{-1}, P=0.01). There were no differences in absolute CHO intake between any other mealtimes and there was no interaction effect between mealtimes and time-points for CHO (P>0.05).

There were no differences between time-point for protein intake per meal (P=0.42). Protein intake was however significantly different across mealtime points ($F_{8,29}$=9.53, P<0.01). There was a significant difference (Table 4.1) in absolute protein intake between breakfast and evening snack (95% CI= 6 to 31 g.day^{-1}, P<0.01) and during training (95% CI=2 to 28, P=0.02). Furthermore, there was a difference between AM snack and dinner (95% CI=-35 to -7 g.day^{-1}, P<0.01). There was a difference between lunch, and evening snack (95% CI=5 to 34 g.day^{-1}, P=0.01) and during training (95% CI=2 to 30 g.day^{-1}, P=0.02). Dinner was significantly different to PM snack (95% CI=-40 to -1 g.day^{-1}, P=0.04) and during training (95% CI=7 to 48 g.day^{-1}, P=0.01). No interaction effect between mealtimes and time-points was detected for protein intakes.

No differences between time-points were detected for fat intake per meal (P=0.23). However, there was a significant main effect (Table 4.1) for mealtimes ($F_{2,20}$ =8.17, P<0.01). There was a significant difference in absolute fat intake between breakfast and evening snack (95% CI=1 to 14 g.day^{-1}, P=0.02) and during training (95% CI= 3 to 14 g.day^{-1}, P<0.01). There was a difference between lunch (95% CI=1 ± 11 g.day^{-1}, P=0.03) and PM snack (95% CI= 1 ± 7, P=0.03). Moreover, there was significant difference between PM snack and during training (95% CI= 1 ± 7 g.day^{-1}, P=0.04). There was no interaction effect between mealtimes and time-points for fat intake.

Table 4.1: *Accumulated means of energy and macronutrient intakes meal distribution on two weekdays and one weekend training days.*

	Time point	Breakfast	AM snack	Lunch	PM snack	Dinner	Evening Snack	Pre-bed	During	Post-training
Energy intake	-12WK	287.1±81.5	178.7±113.0	254.7±118.2	208.4±136.6	337.4±149.5[b#]	61.0±103.1[ac#]	153.3±125.2[a#]	25.9±31.8[aceg#]	191.6±105.2[f#]
(Kcal.meal^{-1})	-4WK	273.0±78.2	155.8±89.3	263.6±158.0	138.1±126.3	306.1±77.1	31.2±40.1	153.6±131.8	27.2±27.4	251.8±134.1
	-1WK	298.4±101.4	138.3±118.7	206.6±127.0	114.3±108.4	252.2±84.1[b#]	36.0±106.1[ac#]	116.9±139.4[a#]	32.3±35.1[aceg#]	177.8±121.3[f#]
Carbohydrate	-12WK	30.7±11.9	21.5±15.2	26.8±20.4	34.1±20.9	42.6±48.0	5.2±11.3[a]	7.3±8.2[a]	0.7±1.3[ad]	26.6±17.8
intake	-4WK	31.1±14.9	17.0±12.9	31.4±24.2	19.4±19.2	22.9±18.8	3.2±5.3[a]	10.7±11.3[a]	1.6±4.0[ad]	33.1±24.9
(g.meal^{-1})	-1WK	32.4±16.9	13.9±17.4	20.7±19.5	12.4±15.9	17.5±15.4	4.2±11.5[a]	7.1±8.5[a]	0.3±0.7[ad]	21.4±23.8
Protein intake	-12WK	23.9±8.9	13.9±10.9	26.0±14.1	17.8±14.1	35.0±15.9[bd]	4.1±9.6[ace]	16.0±13.6	5.8±7.0[ace]	16.2±10.8
(g.meal^{-1})	-4WK	20.8±4.8	15.01±10.6	23.4±13.9	10.1±11.9	38.2±8.5[bd]	2.4±3.2[ace]	15.2±13.2	6.5±6.4[ace]	25.7±12.2
	-1WK	19.9±6.8	10.7±11.2	18.8±9.05	12.9±14.4	29.2±12.6[bd]	2.7±8.0[ace]	13.5±16.2	7.8±8.7[ace]	19.7±14.7
Fat intake	-12WK	8.4±4.9	3.8±2.8	7.5±6.2	5.1±4.8	8.3±6.9	1.0±1.8[a]	6.7±7.2	0.0±0.0[acd]	3.1±2.8
(g.meal^{-1})	-4WK	7.4±2.6	3.4±1.9	4.2±3.2	2.2±2.4	7.4±7.4	0.8±1.4[a]	5.4±6.4	0.0±0.0[acd]	3.3±2.5
	-1WK	9.8±6.4	3.6 ±3.2	5.4±4.7	3.1±5.5	5.4±5.9	1.0±3.1[a]	3.8±5.1	0.0±0.0[acd]	3.4±4.2

[a]denotes difference from breakfast, [b]denotes different from AM snack, [c]denotes difference from lunch, [d]denotes difference from PM snack, [e]denotes difference from dinner, [f]denotes difference from evening snack, [h]denotes pre-bed intake, and [g]denotes difference from post-training. # denotes significant difference between time points.

4.3.4 Nutritional supplements

All athletes in the present study reported consuming multiple nutritional supplements in the pre-competition period. Protein supplements (whey proteins) were the most frequently consumed supplement (100%), followed by caffeine (88.9%) in the form of energy drinks, over-the-counter fat burners and coffee, and Vitamin C (67%). Furthermore, 56% of FP athletes consumed branched-chain amino acids (BCAAs) during training, conjugated linoleic acid, multivitamin/mineral complex supplements, Vitamin $D_{3,}$ and Omega 3 oils. While 33% of FP athletes reported using Glucosamine, L-carnitine and Glutamine and 22% of FP athletes used creatine supplementation during the pre-competition period.

4.3.5 Self-reported training duration, load and volume

Accumulated ($F_{2,14}$=3.71, P=0.05) aerobic training duration (Figure 4.4A) was significantly lower at -12WK (99.4 ± 67.7 min) compared to -4WK (168.3 ± 84.9 min; 95% CI=-125.85 to -11.92 min; P=0.02; ES=-0.85, 95% CI= -1.82 to 0.11). However, there was no difference between -4WK and -1WK (P=1.00; ES=0.04, 95% CI= -0.89 to 0.96) or between -12WK and -1WK (P=0.24; ES=-0.99, 95% CI=-1.97 to -0.01). Accumulated ($F_{2,16}$=2.63, P=0.10) aerobic training sRPE (Figure 4.4B) was similar across time-points. Aerobic sessions (between 06:00 - 09:00 AM) were performed in a fasted state, or immediately after resistance training (at -12WK). Resistance training was performed after breakfast, lunch or PM snack at -12WK, -4WK and -1WK.

Accumulated ($F_{2,16}$=8.63, P<0.01) resistance training duration (Figure 4.4C) was significantly greater at -4WK (232.4 ± 58.3 min) compared to -1WK (166.3 ± 34.6 min; 95% CI=9.1 to 123.2 min; P=0.02; ES =1.31, 95% CI= 0.29 to 2.33). However, accumulated resistance training duration was similar between -12WK and -4WK (P=0.76; ES=-0.23, 95% CI= -1.15 to 0.70) and between 12WK and -1WK (P=0.07; ES =0.95, 95% CI= -0.03 to 1.92). Accumulated ($F_{2,15}$=23.65, P<0.01) resistance training sRPE (Figure 4.4D) was significantly greater at -12WK (1555 ± 672 arbitrary units (AU)) compared to -1WK (377 ± 161 AU; 95% CI = 534 to 1,822 AU, P<0.01; ES=2.30, 95% CI = 1.11 to 3.49). Similarly, -4WK (1675 ± 749 AU) was also significantly greater than -1WK (95% CI = 546 to 2,049 AU, P<0.01; ES= 2.28, 95% CI = 1.09 to 3.47). There was however no difference between -12WK and -4WK (P=1.00; ES= -0.16, 95% CI = -1.09 to 0.77).

Accumulative ($F_{2,16}$=3.17, P=0.07) TV (Figure 4.4E) and average ($F_{1,9}$=1.77, P=0.22) TV (Figure 4.4F) was not different between any time-points. Average ($F_{1,10}$=1.80, P=0.22) TV index (Figure 4.4G) independent from BM, was also similar between time points. Frequency (P=0.72) of weekly rest days were similar at -12WK (2 ± 1 days), compared to -4WK (2 ± 0 days, P=1.00; ES=0.00), and -1WK (1 ± 1 days, P=1.00). Similarly, -4WK was not different to -1WK in weekly rest days (P=1.00). Athletes performed a consistent blend of upper-, lower- and whole-body training days throughout -12WK and -1WK (*e.g.,* upper body on Monday and Thursday, lower body on Tuesday and Friday and lower body or whole-body Saturday) which was individually selected and repeated weekly. These sessions included body weight, free weights and resistance machine-based exercises.

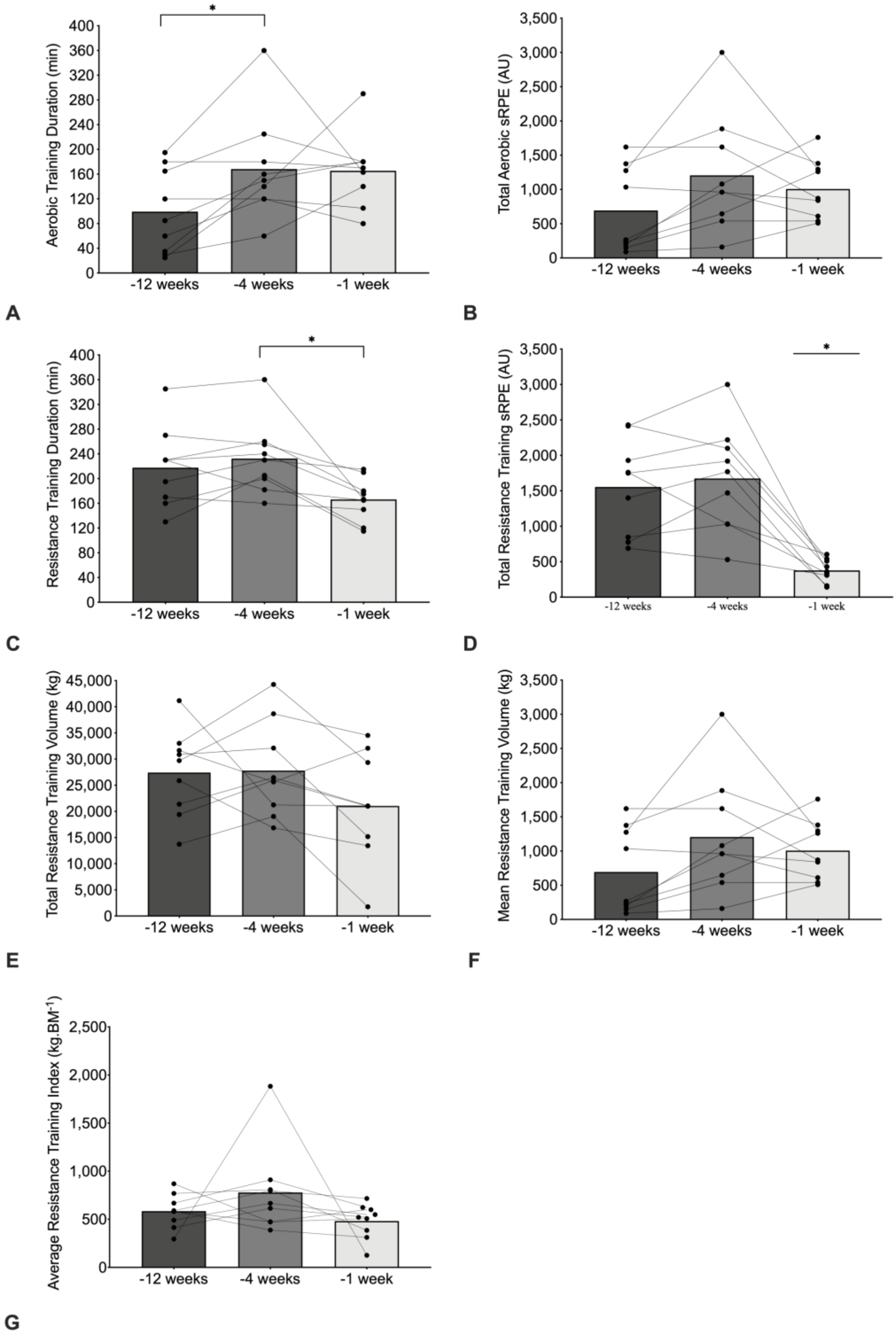

Figure 4.4 *— Average training duration, sum and average training volume, sRPE and index across -12 weeks, -4 weeks and -1 week pre competition in female physique athletes. Figure 4.4A= Average training duration in aerobic sessions, Figure 4.4B= Total sRPE in aerobic exercise session (completed in the morning in a fasted state or immediately after resistance training session at -12WK), Figure*

*4.4C= Average training duration in resistance training sessions, Figure 4.4D= Total sRPE in resistance training sessions, 4.4E= Total training volume in resistance training sessions (repetitions x sets x weight), 4.4F= Average training volume in resistance exercise sessions (repetitions x sets x weight) and 4.4G=Average training index in resistance training sessions. * (with line) denotes significant difference (P<0.05) compared to the other time-points.*

4.3.6 Perceived psychological wellbeing and mood states

Mean Daily Well-being scores ($F_{1, 11}$=1.53, P=0.25) were similar across all time-points. Additionally, TMD scores ($F_{1,11}$=1.90, P=0.20) were similar across all time-points. Within the mood sub-scales, vigour was significantly reduced from -12WK (8 ± 3 AU) to -1WK (5 ± 2 AU; 95% CI=0 to 6 AU; P=0.01; ES=1.09, 95% CI = 0.10 to 2.08), while there was no difference between -12WK and -4WK (P=0.72; ES=0.32, 95% CI = -0.61 to 1.25) and -4WK and -1WK (P=0.06; ES=0.72, 95% CI = -0.23 to 1.68). No significant differences were detected in any other mood sub-scales (P>0.05).

Table 4.2: *Daily well-being and mood states of female physique athletes*

	-12WK	-4WK	-1WK
Daily well-being score (AU)	15 ± 3	15 ± 3	13 ± 4
TMD score (AU)	16 ± 8	19 ± 9	24 ± 13
***Vigour (AU)**	8 ± 3	7 ± 3	5 ± 2[a]
Anger (AU)	3 ± 2	4 ± 3	3 ± 3
Depression (AU)	2 ± 3	2 ± 3	5 ± 5
Tension (AU)	2 ± 3	5 ± 4	7 ± 5
Fatigue (AU)	8 ± 4	8 ± 4	10 ± 3
Confusion (AU)	2 ± 3	3 ± 4	6 ± 5

*Significantly different between time-points. [a] Significantly different to -12WK. TMD= Total mood disturbance

4.4 Discussion

Using a longitudinal observational study design, this study provides novel data on the nutrition, training, well-being and mood states of FP athletes during a pre-competition phase. During the 12-week pre-competition phase, FP athletes reduced their BM which coincided with reductions in absolute mean EI via a reduction in absolute fat and protein intake. Additionally, FP athletes reduced resistance TL at the end of pre-competition and increased aerobic exercise duration at the beginning of pre-competition. As a result, FP athletes only showed a moderate change in vigour.

In the present study, FP athletes decreased BM from 60.9 to 55.6 kg (~ 0.4 kg ^{1}.week^{-1} $^{-}$over 12-weeks), with one participant reducing from 60.1 to 48.4 kg (~ 1 kg.week^{-1}), due to a prolonged energy deficit at (-12WK = -453 kcal.day^{-1} and -4WK = -428 kcal.day^{-1}) (Fagerberg, 2018). These findings confirm previous case-reports (Halliday et al., 2016; Tinsley et al., 2019) showing that FP athletes use a fluctuating dieting approach to reduce BM during the pre-competition. The large individual variation in energy deficit and BM changes might be the result of the starting body composition as FP athletes enter the pre-competition phase. For example, if a FP athlete has accumulated excessive FM during the off-season, they may strategically adopt a more aggressive approach to decreasing BM during the pre-competition phase via severe energy restriction and excessive exercise behaviours; however, this is yet to be studied.

To favourably manipulate body composition (maintain/increase FFM and reduce FM) in the pre-competition period, dietary strategies are often carefully planned and structured (Spendlove et al., 2015). With a large change, athletes in this study decreased EI from -12WK to -1WK (1738 to 1379 $kcal.day^{-1}$; P=0.03; ES=1.31), although there was no change in relative terms. Two FP athletes reported the greatest reductions in daily EI of approximately 800-1000 $kcal.day^{-1}$ from the start to the end of the 12-week pre-competition phase, resulting in intakes of 1081 $kcal.day^{-1}$ (22 $kcal.kg^{-1}$ $BM.day^{-1}$) and 1113 $kcal.day^{-1}$ (18 $kcal.kg^{-1}$ $BM.day^{-1}$) at -1WK prior to competition, respectively. In contrast, seven of the other participants only reduced with < 500 $kcal.day^{-1}$ from the start to the end of pre-competition. Case reports have shown in one individual, the EI changed by △85$kcal.day^{-1}$ (Petrizzo et al., (2017) which is greater than in another individual who changed by △645 $kcal.day^{-1}$(Tinsley et al., 2019a). Discrepancies in the degree of caloric restriction may be due to the division the athletes were competing in. For example, in both Petrizzo et al., (2017) and Tinsley et al., (2019b) a single female athlete competing in the Figure division were assessed. It may also be dictated by the starting body composition (baseline) and the diet duration allowing for a more drastic weight loss in the pre-competition phase. Finally, comparing the studies may be challenging due to the methods used to assess EI in these case reports (nutritional plans prescribed by coaches submitted to research studies *vs.* prospectively writing the nutritional intakes) (Petrizzo et al., 2017; Tinsley et al., 2019b). These strategies might not represent the actual dietary intakes that FP athletes consumed unlike direct measurement of EI (via weighed food diary followed by a 24-hours recall) in the present study.

During the pre-competition phase, FP athletes consumed low to moderate daily CHO intake (2.3-2.9 $g.kg^{-1}.day^{-1}$) as defined by Burke et al., (2006) which did not change across time-points. However, it is worth noting that seven out of nine FP athletes lowered daily CHO intake by an average of 46 $g.day^{-1}$ during the pre-competition phase. While this may not appear a large amount to an average person, it may make a practical aesthetic difference daily for a physique athlete with already low FM close to competition (Mitchell et al., 2017). One athlete reduced total daily CHO intake from 138 g to 26 g (2.3 $g.kg^{-1}.day^{-1}$ to 0.5 $g.kg^{-1}.day^{-1}$) (~81% reduction) which is substantially lower than the CHO recommendations (5-7 $g.kg^{-1}.day^{-1}$) for physique athletes (Slater and Phillips 2011) and what is classed as a ketogenic diet (<50 $g.day^{-1}$) (Paoli et al., 2021).

While low unchanged relative intake of CHO over time were observed, there was a tendency for some individuals (n=2) to consume greater CHO intakes at -1WK (~ 4 $g.kg^{-1}.day^{-1}$) which is a known technique used to elevate muscle glycogen for the outcome of increasing muscle size for competition (de Moraes et al., 2019). These disparities in approaches between individuals may have contributed to the lack of observed significance between -12 WK and -1WK. A recent study by Paoli et al., (2021) showed that nine male non-competitive (off-season) bodybuilders consuming a ketogenic diet (5% CHO of EI per day equivalent to < 50 $g.day^{-1}$) reduced FM significantly with no changes to FFM (using bioelectrical impendence analysis) compared to the matched-participant group western diet (representing 55% CHO of EI per day). Future research should investigate if low CHO availability negates muscle definition and size in competition in females.

In relation to daily nutrient distribution, FP athletes distributed their CHO differently between mealtimes, although this did not change across time-points. CHO intake was greater at breakfast (31.4 ± 13.0 $g.day^{-1}$), dinner (27.7 ± 18.7 $g.day^{-1}$) and post-training (27.0 ± 18.8 $g.day^{-1}$), compared to evening snack (4.2 ± 5.4

g.day^{-1}) and pre-sleep (8.4 ± 7.3 g.day^{-1}), which is consistent with a previous case report observation (Halliday et al., 2016). It is speculated whether FP athletes practice low CHO intakes during the evening, followed by an overnight fast prior to morning aerobic exercise in the awareness that lipid oxidation can be enhanced (and therefore FM reduction) due to low-CHO availability (Heikura et al., 2017).

Timing of protein intake is another important consideration during energy-restricted periods to minimise reductions in FFM (Res et al., 2012; Trommelen et al., 2018). Despite FP athletes did not change their protein intake (relatively) across time (although a moderate change was seen in absolute terms between -12WK and -1WK), athletes met or exceeded daily protein recommendations (Hector & Phillips, 2018) during all time-points in pre-competition (>2.4 g .kg^{-1}day^{-1}). This finding agrees with previous work on physique athletes (Mitchell et al., 2017; Chappell et al., 2018). A higher consistent protein requirement may be justified for physique athletes in pre-competition to prevent loss of LBM during energy restriction (Helms et al., 2014).

Consuming evenly spaced feedings (rather than a skewed pattern) containing 20 g of high-quality protein throughout the day is considered most effective for maximising stimulation of MPS post-exercise in males (Areta et al., 2013; Mamerow et al., 2014). Athletes consumed consistent amounts of protein in breakfast, lunch and dinner throughout the day which did not change between time-points. Yet, it should be noted that four athletes did not consume any protein (0 g) at evening snack and prior to sleep at -1WK. In this context, the late (PM) training sessions or other activities (i.e., work) may have influenced the athlete's appetite or access to food in the evening window. Therefore, FP athletes may benefit from higher protein intakes in the evening and pre-bed windows to better facilitate post-exercise muscle recovery and optimise muscle protein remodelling (Res et al., 2012; Roberts et al., 2020). Daily fat intake was reduced in absolute terms (12WK to -1WK), however, this remained unchanged in relative terms within-daily distribution across time. Dietary fat is often the last macronutrient of concern for physique athletes since protein and CHO may help them preserve LBM, increase satiety, and aid training performance (Roberts et al., 2020).

Aerobic training duration was lower at -12WK (33 $min.day^{-1}$) compared to the two other time-points (-4WK: 56 $min.day^{-1}$; -1WK: 55 $min.day^{-1}$). While the duration of resistance training was lower at -1WK (55 $min.day^{-1}$) compared to -4WK: (77 $min.day^{-1}$), there was a ~ 77% reduction in the sRPE (377 AU) at -1WK compared to -12WK (1555 AU) and -4WK (1674 AU). Despite a periodised pre-competition approach to aerobic and resistance training durations and loads, FP athletes performed similar absolute and relative resistance TV across time points, as is similarly observed in male counterparts (Hackett et al., 2013; Kistler et al., 2014; Mitchell et al., 2018). Previous studies have shown that concurrent high-volume aerobic and resistance exercise within close proximity is likely to attenuate resistance training adaptations such as muscular hypertrophy and strength development (Bell et al., 2000; Murach & Bagley, 2016) and increase neuromuscular fatigue. Subsequently, this may compromise LBM and increase injury risks during their second session (Taipale et al., 2014). However, it is questionable whether adequate quantity and timing of protein ingestion would counter the catabolic effects of concurrent training in a negative energy balance and hence assist in the maintenance of LBM (Areta et al., 2014).

Both psychometric measures (daily well-being and mood states assessments) showed no changes from the start to the end of the pre-competition phase in nine FP athletes, although a reduction in vigour from -12WK (8 ± 3AU) to -1WK (5 ± 2AU) was observed. These findings are similar to research conducted on a large group of FP athletes (Hulmi et al., 2016) showing no change in mood states across different competitive seasons. This contrasts with case reports on physique athletes (Rohrig et al., 2017; Rossow et al., 2013). Individual responses to dieting, and the severity and duration of energy deficit and CHO restriction (O'Leary et al., 2020) may account for this. For example, the individuals in the case reports had a 5–6 months of pre-competition while Hulmi et al., (2016) and the present study had a 3-month pre-competition phase.

In this study, all data was self-reported, however to minimise potential errors in reporting EI, the lead researcher used two different methods (*i.e.,* three-day food diaries and weighed food inventories) and also performed 24-hr recall after each time-point (Capling et al., 2017b). Secondly, it was not possible to provide all participants with SECA scales for BM measurements at each time-point. However, in the laboratories, a comparison between the SECA (model-875, Germany) and commercialised (unbranded Amazon) scales on a small number of participants (n=10) with different BM, was made and seemed to compare favourably (with a mean difference between the scales = 0.15kg). Thirdly, three-day data collection may be considered a limitation, although in the real world of data collection, three-days has been suggested to promote better adherence than a seven-day collection period (Capling et al., 2017b). Furthermore, considering physique athletes routinely select similar food types, consume similar amounts each day and routinely repeat their weekly training sessions (Helms et al., 2014) and are known for rigorous adherence to their detailed training and nutrition plans (Mathissen et al., 2019), it is believed that the data collected represents habitual dietary and training estimates of FP athletes. Lastly, it was not possible to measure body composition (*i.e.*, FM and FFM) during the pre-competition phase in this study, and therefore it is unknown whether these athletes' nutritional and training strategies enabled them to preserve LBM during this period.

4.5 Conclusion

In summary, during a 12-week pre-competition phase, FP athletes reduced EI predominantly via protein and fat intake, alongside reduced resistance TL and increased aerobic exercise duration, and decreased BM. As a result, no changes were observed in daily well-being or mood states (except for reduced vigour) during the pre-competition phase. The data can improve knowledge of FP athletes and coaches working with FP athletes regarding within-day energy balance (*ie.*, improved energy availability), nutrient timing (*i.e.*, consistent protein intakes throughout the day) and training practices (*i.e.*, manipulation of training load and duration). To achieve the body composition ideal and improve/maintain the health of FP athletes during prolonged periods of energy restriction, nutritional and training plans may follow a periodised approach to energy availability (to avoid constant LEA) with high fuel around exercise and lower fuel availability outside of training (Impey et al., 2018) and evenly consistent distributed protein intake across the day (Hector & Phillips, 2018).

[redacted]5. The physiological and psychological responses of an international female physique athlete pre-, during- and post-competition: A case report

5.1 Introduction

Low energy availability, stemming from reduced energy intake and increased exercise (or a combination of both) is the underlying cause for various psychophysiological dysregulations and performance impairments characterised within The Female and Male Athlete Triad (Nattiv et al., 2021) and RED-S frameworks (Mountjoy et al., 2018). Female athletes emphasising leanness have been reported to have an increased risk for LEA (Sundgot-Borgen et al., 2011). Furthermore, many FP athletes experience BM and FM overshoot in the recovery phase from refeeding practices, which may compromise cardiometabolic health, obesity in later life, and disturb perception of body image and eating behaviours (Mathisen & Sundgot-Borgen, 2019). Previous work, including study 2 of this thesis (Chapter 3) have revealed issues with DE/ED and binge eating in FP athletes, raising concerns for their health. Physiological and psychological health variables in FP athletes during various competition phases, including those indicative of RED-S, remain insufficiently researched (Mathisen et al., 2019).

Study 2 (sections 4.3.2 and 4.3.5), an observational report showed changes in EI and training variables to achieve body composition aspirations in nine FP athletes at different time points in the pre-competition phase. The study has highlighted that the pre-competition phase is characterised by reduced BM and EI (although not relative to BM) which are concurrent with increased aerobic exercise duration and reduced resistance training loads. These practices provide an opportunity to gradually reduce FM through an accumulated energy deficit, whilst minimising LBM loss (Helms et al., 2014) with only vigour (out of all mood states measured) being affected. However, some FP athletes may have a shorter time period to meet the division-specific body composition requirements and therefore may induce greater magnitudes of energy deficits (Lapinskienė et al., 2018; Robinson et al., 2015). In such circumstances, FP athletes may increase the likelihood of suffering from negative consequences of prolonged exposure of LEA (Mathisen et al., 2019; Tinsley et al., 2019a), thereby manifesting as health implications associated with the RED-S symptoms (Hulmi et al., 2017; Halliday et al., 2016). Furthermore, extended and intensive periods of energy restriction may also result in rebound hyperphagia following competition (Mathisen & Sundgot-Borgen, 2019) which is experienced for some athletes in the present thesis (Chapter 6).

FP athletes employ an array of strategies to engage in both chronic and acute weight loss, in the hope to become leaner (section 3.3.3). Albeit many of these strategies may not be supported by strong scientific underpinning, thus athletes put their health in jeopardy in pre-competition (Mitchell et al., 2017; Probert et al., 2007). In the final pre-competitive phase (*i.e.,* competition week), FP athletes may use water, sodium, CHO manipulation loading, diuretics and laxatives manipulation to acutely enhance muscle size and increase leanness (via increases in muscle glycogen concurrent with losses in body water) for competition day (Chappell & Simper, 2018; de Moraes et al., 2019). Although previous research has questioned the effects on health and safety of water loading (Reale et al., 2018; Shephard, 1994), limited research has investigated the changes in hydration status and renal function in female athletes employing real-life water loading strategies. Given the observed prevalence of water loading in study 1 (section 3.3.3), it is important to scientifically investigate real-life water loading practices and the potential risk of hyponatremia associated with the consumption of substantial volumes of fluid.

Few case studies have comprehensively examined the competition week or longer-term recovery (>10 weeks) from a physique competition (Halliday et al., 2016; Tinsley et al., 2019a). Yet, these studies have only assessed the Figure division (where muscularity and leanness requirements are less emphasised, see section 2.3 for a description of the body composition requirements). Each division within the sport has different judging criteria, which may dictate the selected dieting and training practices employed by the athletes, and therefore, may result in different physiological and psychological responses pre- and post-competition. Moreover, the cited case reports (Halliday et al., 2016; Tinsley et al., 2019a) have not assessed biomarkers relevant to fluid manipulation, RED-S symptoms and weight restoration such as renal function, hydration, endocrine status, micronutrient status and cardiometabolic health. To authors' knowledge, this level of detail has not been explored in FP athletes in the existing literature. The value of case reports in elite female athletes has recently been highlighted (Burden et al., 2021). This is important as they can provide practitioners and clinicians detailed insights into individual cases to guide clinical interventions and real-world applications.

Therefore, the aim of the present case study report was to assess the anthropometric, physiological and psychological effects of an experienced international FP athlete during three phases of the competitive year/cycle, representing a brief snapshot of pre-competition phase (Phase 1), a competition week (Phase 2) and a recovery phase (Phase 3).

5.2 Athlete Overview

A Caucasian FP athlete (age: 28 years, BM: 57.4 kg, height: 156.2 cm) competing in the Bikini Fitness division in the IFBB organisation participated. The athlete was experienced (4 years of competitions including 6 competitions at the international level) and informally reported habitually losing 8-12 kg of BM across phases of 12-16 weeks prior to competition. The initial intention of this case report was to investigate a group of six FP athletes, but due to a high drop-out rate, only one individual completed the study. Out of the six individuals enrolled, five dropped out for various reasons: limited time availability due to travel, parenting, and full-time jobs (n = 2); competition cancellation (n=1), and sudden use of IPEDS (n=2). which was an exclusion criterion of the study. This observational case report aimed to document the athlete's changes in self-reported energy intake, anthropometric characteristics, resting metabolic rate, hydration status, blood biochemistry, self-reported menstrual cycle, mood states and sleep quality before, during and after the IFBB professional league qualifiers (Romania Muscle Fest qualifiers, 2018). The study was only able to collect data starting from -4 weeks before the competition (due to a late decision to compete). As a result, it is crucial to acknowledge that there is no true baseline for the current study and the observed data may not fully reflect the complete ranges of changes. The athlete stated that her aim was to win the IFBB professional league qualifiers competition in the Bikini Fitness division by achieving the aesthetic ideal (manipulate body composition) and no attempt was made to provide advice or intervene.

5.3 Methods and Materials

5.3.1 Research design

The athlete attended the laboratory on five occasions and undertook assessments for EI, training practices, anthropometry, resting metabolic rate, hydration, risk of LEA, endocrine status, micronutrient status, lipid profiles, renal and liver biomarkers and psychometric parameters (sleep quality and mood profiles). Assessments were undertaken at 4 weeks (-4WK) (Phase 1) prior to competition, 7 days prior to competition (-1WK), two days before weigh in and competition day (-2D) (Phase 2) and again at 4 weeks (+4 WK) and 12 weeks (+12 WK) post-competition (Phase 3) at the same time of day (between 07:00-09:00) following an overnight fast (Figure 5.1). These time-points were selected due to being representative of the different competition cycle phases (pre-competition, competition week and recovery) and the feasibility of the athlete to visit the institute laboratories. Although the athlete started dieting earlier than -4WK time-point, it was only later that the athlete decided to compete on a specific date, and therefore invited to participate in the study. As such a true baseline was not measured in the present study. The athlete was informed about all aspects of the study, provided written consent, and this case report was approved by LJMU Human Ethics Committee (Project: TPL/006).

5.3.2 Self-reporting dietary intake and training characteristics

The athlete was instructed to complete a 7-day dietary record (diet records with weighed food inventory) using paper and pen before arriving to the laboratories on the day of testing (*ie.*, dietary records at -5WK to -4WK; -2WK to -1WK; -1WK to -2D; +3WK to +4WK; and +11WK to +12WK). In cases, where obtaining a 7-day dietary record was not feasible (*ie.*, at the -2D time-point), a 5-day dietary record was obtained instead. The athlete received detailed instructions at pre-screening before the first visit on how to complete records and were subsequently asked to accurately record information on: Timing, quantity and type of foods and beverages consumed and brands of commercial and ready-to-eat food items and supplements, preparation methods (cooking oils etc.) and any leftovers unfinished food and drink (if appropriate). Guidelines were provided by a registered nutritionist (SENr). The 7-day food diaries were analysed using a nutritional dietary analysis software (Nutritics^{TM}, Dublin, Ireland) for daily nutrient intakes by two SENr practitioners to ensure the validity of transferring a written food log to the software (this resulted in a CV< 5% between the practitioners for all macronutrients and total energy intake per day). When elements of the food records were unclear, the researcher contacted the athlete to ask for more information (*e.g.*, photographs of the brands consumed; quantity of supplements/ sauces used). Type, brand and dosage of nutritional supplement use were reported each day of the study period in the written food diaries.

5.3.3 Anthropometric measurements

Body mass (SECA, model-875, Germany) and stature, using a free-standing stadiometer (SECA model-719, Germany), were measured to the nearest 0.01 kg and 0.1 cm respectively, at every time-point (wearing shorts and sports top only). Skinfold thickness assessment was measured via anthropometric sum of 8-skinfold sites ($\sum_{8SKf}$) using a skinfold calliper (Harpenden, Baty Int., West Sussex, Great Britain) according to the International Society Advancement Kinanthropometry (ISAK) protocols (Marfell-Jones et al., 2006) by an ISAK Level 1 practitioner. To reduce inter-variability, the same practitioner collected measurements on the right side of the body with the athlete standing upright and relaxed. Duplicate measurements were taken for each landmark site. A third measurement was performed if the measurement 1 and 2 were greater than 5% variance. Where two measurements were taken, the mean was recorded. Relative technical error of measurement (TEM) was 0.21% (-4WK), 0.10% (-1WK), 1.29% (-2D), 0.04% (+4WK) 0.98% (+12WK). Intra-practitioner coefficient of variation (CV) for $\sum_{8SKf}$ was <1.30% for repeated measures of each site of skinfold measurements. Based on the ISAK guidelines, girth circumferences for chest, waist, hips and calves were measured in triplicates and the median value of the measurements was recorded. These sites were selected in the present study due to their relevance in the competition judging criteria for FP athletes (Alwan et al., 2019).

5.3.4 Resting metabolic rate (RMR) and Ratio (RMR_{ratio})

Measured RMR (RMR_{meas}) was assessed via indirect calorimetry (GEM Open Circuit Indirect Calorimeter, GEM Nutrition Ltd. UK) using a protocol proposed for athletic populations (Bone and Burke 2017), and calibrated as previously described (Langan-Evans et al., 2020). Briefly, athletes were rested in a supine position for ~15 min before data collection in an isolated laboratory room with controlled ambient temperature, low lighting and noise (Compher et al., 2006). A ventilated hood was placed over the participants' head for another 15 minutes with the first 5 minutes being discarded, and the remaining 10 minutes required to have a CV of < 5% to be used (Haugen et al., 2003). Oxygen consumption and carbon dioxide production was collected at 1 min intervals and RMR was expressed as a predicted percentage using the Cunningham equation (Cunningham 1980). The test-retest reliability has previously been reported as 6.9% CV for RMR on the GEM system by Kennedy et al., (2014). RMR_{pred} was established using the Harris-Benedict equation BM equation which has yielded good-acceptable sensitivity

(0.87) in exercising women (Strock et al., 2020b) as defined in Strock et al., (2020a). RMR_{ratio} was established by dividing RMR_{meas} with RMR_{pred}, where values of ≤0.90 are indicative of potential energy deficiency (Strock et al., (2020a); Monica Klungland Torstveit et al., 2018).

5.3.5 Hydration status

The athlete was instructed to provide a urine sample from middle flow of the initial urine output upon waking at -4WK, -1WK and -2D. Hydration status was not measured at +4WK and +12WK time-point visits due to no manipulation of fluid or salt in the recovery phase (Escalante et al., 2021). Urine samples were measured for osmolality (U_{osm}) using a freezing point depression osmometer (Roebling, Camlab UK) as previously described (Sparks & Close, 2013). Urine specific gravity (U_{usg}) was measured with a digital handheld refractometer (Atago 4410 Urinary Specific Gravity Refractometer, Bellevue, WA, USA) as per manufacturer's instructions. For both methods, duplicate measurements were averaged (CV= 0% across all time-points between two measurements). Dehydration was considered as U_{usg} ≥ 1.020 g.ml^{-1} and overhydration was defined as U_{usg}: 1.001-1-012 g.ml^{-1} (Hew-Butler et al., 2018). Electrolyte imbalances were measured using serum blood samples.

5.3.6 Blood sampling and analysis

Fasted blood samples were obtained from the antecubital vein and collected into EDTA (for plasma) and serum separation tubes (Becton-Dickinson BD, Franklin Lakes, USA) as previously described (Wilson et al., 2013). EDTA Blood samples were centrifuged for 15 min at 4°C to harvest the plasma, whilst blood samples for serum separation were left at room temperature for 30 min prior to the same centrifugation procedure. Samples were then individually aliquoted into 1.5 ml Eppendorf tubes (Eppendorf UK Limited, Stevenage, Great Britain) and stored at -80°C for subsequent analysis. Biomarkers measured included ferritin (FE), iron, vitamin B12 (B12) and folate, renal biomarkers, liver function tests (LFT), calcium (adjusted for serum albumin), lipid profile, magnesium (Mg), luteinizing hormone (LH), follicle-stimulating hormone (FSH), oestradiol (E2), prolactin (PRL), cortisol (C), progesterone (PROG), testosterone (T), sex hormone binding globulin (SHBG), insulin (I), insulin-like growth factor-1 (IGF-1), free thyroxine (FT4), free triiodothyronine (FT3), creatine kinase (CK), c-reactive protein (CRP), and Total 25 Hydroxy-Vitamin D (25(OH)$D_{2,3}$) (Serum total 25(OH)D). The following markers: FSH, LH, Folate, B12, FE, E2, FT4, FT3, C, B12, PRL, PROG, I and SHBG were assessed via immunoassay with chemiluminescence detection on a Roche Cobas e601/602 Modular analyser (Roche Diagnostics Ltd. Burgess Hill, UK) and IGF-1 on an IDS iSYS Analyser (Immunodiagnostic Systems Holdings plc., Tyne & Wear, Great Britain). While Mg, adjusted calcium and iron status were assessed via Roche/Hitachi cobas c501/502 analyser (Roche Daignostics Ltd, Burgess Hill, Great Britain) utilising a 2 Point End assay. Similarly, Albumin (ALB), Bilirubin (BIL), CRP, total protein (TP), and Total Cholesterol (CHOL) were assessed on cobas c501/502 analyser using a Rate A, 2-point and 1-point End assays, respectively. Phosphate (PHOS), CK, CRP, Alanine Aminotransferase (ALT), Alkaline Phosphatase (ALP), Urea, Bilirubin (BIL), Creatinine (CRE), TP, globulin (GLOB), bilirubin (BR), total cholesterol (TC), High Density Lipoprotein cholesterol (HDL-C), Low Density Lipoprotein Cholesterol (LDL-C) and Triglyceride (TG) were all analysed on a Roche Cobas c701/702 Modular analyser

(Roche Diagnostics Ltd. Burgess Hill, Great Britain) utilising Rate A, 1 Point and 2 Point End assays. Na, K, and Cl were examined via potentiometry ion selective electrode (ISE) on a Roche Cobas ISE analyser (Roche Diagnostics Ltd. Burgess Hill, Great Britain). Serum total 25(OH)D and T were analysed by liquid chromatography tandem mass spectrometry (HPLC system, Waters Acquity UPCL chromatography system, Wilmslow, Great Britain). Individual inter/intra assay CV and sensitivity (replicates of the zero standard) are all presented in appendix 9.7 (Chapter 9). All biochemical measurements were conducted by the Royal Liverpool University Hospital with assistance of laboratory staff.

5.3.7 Menstrual cycle history questionnaire and the low energy availability in females questionnaire

The athlete reported having used a non-hormonal copper coil for three years and 6 months at the -4WK time-point and continued to use this type of contraception throughout the study period. Therefore, a menstrual cycle (MC) history questionnaire designed for the purpose of the study was used at every time-point (appendix 9.7, Chapter 9). The 25-item low energy availability questionnaire in females questionnaire (LEAF-Q) (appendix 9.6, Chapter 9) was completed in Phase 1, 2 and 3, which measures occurrence of injuries, gastrointestinal function, menstrual irregularities in female athletes (Melin et al., 2014) (Cronbach's $\alpha \geq 0.71$) to detect whether athletes were at risk of LEA. The LEAF-Q has been validated to be used in endurance athletes (Melin et al., 2014) and therefore, cannot be used as a surrogate diagnostic tool or to classify "high risk" of conditions associated with LEA in FP athletes (Rogers et al., 2021). Nevertheless, it can be used to provide information on overall female athlete health and assess whether FP athletes are at "low risk" of LEA related conditions (Rogers et al., 2021). A total LEAF-Q score of ≥ 8 suggests the athlete is at risk for LEA.

5.3.8 Mood states and sleep quality

Assessment of athletes' mood was evaluated via the BRUMS, an altered short version of the Profile of Mood States questionnaire (Terry et al., 1999). The short-form version was administered to reduce time demands on the athlete without compromising reliability and validity (athletic population Cronbach's $\alpha > 0.70$ and CV ranging from 0.26-0.53 over a 1-week period) (Terry et al., 2003; Terry et al., 1999) and use in physique sport studies (de Moraes et al., 2019; Robinson et al., 2015). Full details of BRUMS have been previously described (section 4.2.6). Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) was used to assess sleeping quality and disturbances (Cronbach's alpha = 0.83). The questionnaire comprised 11 questions grouped into seven domains of sleep-related complaints (*e.g.,* self-reported sleep latency, duration of sleep, usual sleep efficiency and use of medication to sleep). A total score between 0-4 and 5-7 implies good sleep quality and moderate sleep quality, respectively, whereas a total score between 8-21 implies poor sleep quality and risk of a sleeping disorder.

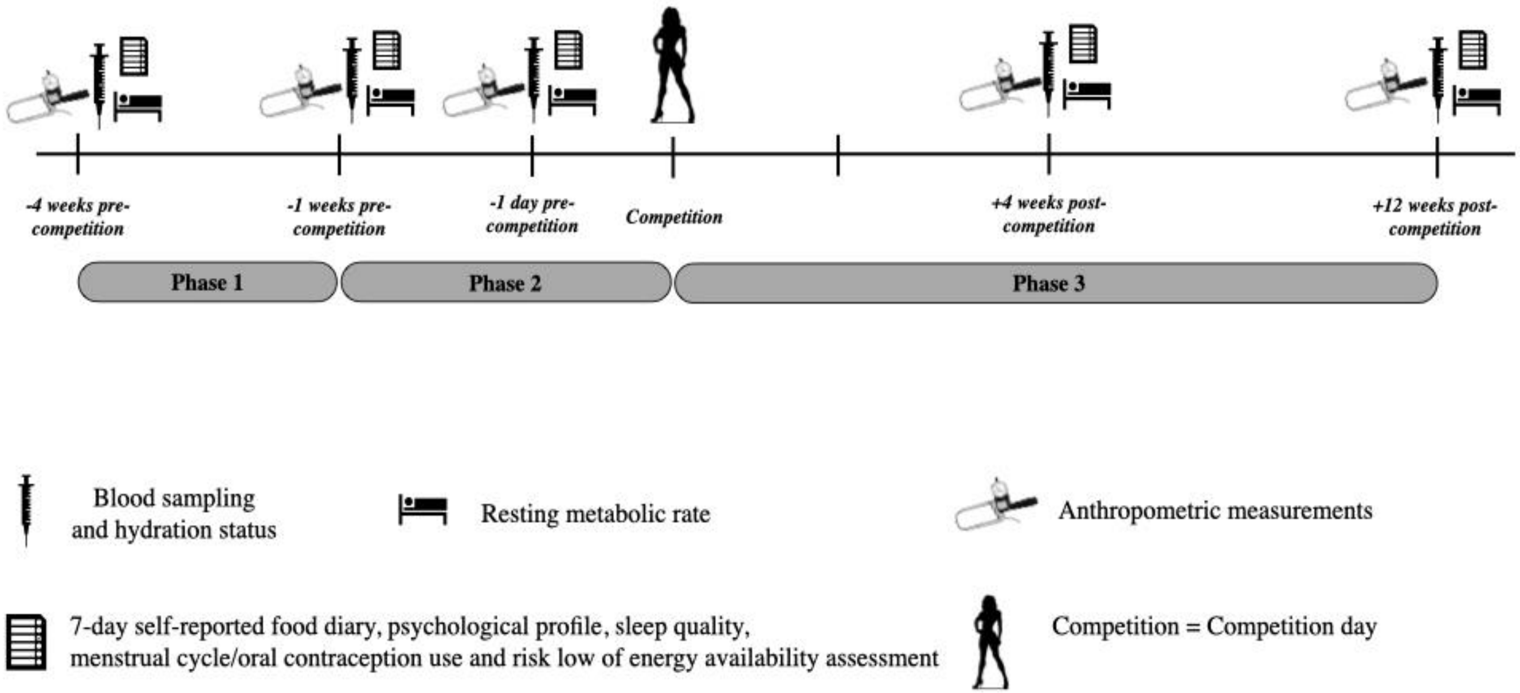

Figure 5.1*— Illustrates laboratory methods and materials used throughout pre-competition (Phase 1), competition week (Phase 2) and post-competition recovery period (Phase 3) of an experienced FP athlete competing at the IFBB professional qualifier competition*.

5.3.9 Data Presentation

Descriptive statistics are presented as mean ± SD. Time-points averages (*i.e.,* -4WK, -1WK, -2D, +4WK and +12WK) for absolute and relative EI, CHO, fat and protein intakes, aerobic and resistance training durations, aerobic and resistance training sRPE and mood states are presented in tables. A low, moderate and high CHO intake was represented as <3 $g.kg^{-1}$, 3-5 $g.kg^{-1}$ and >5 $g.kg^{-1}$, respectively (Burke et al., 2011). A low, moderate and high protein intake was represented as ≤ 1.2 $g.kg^{-1}$, 1.2-2 $g.kg^{-1}$, and ≥2 $g.kg^{-1}$ (Phillips, 2004, 2006). Water loading techniques (Phase 2) were described in terms of daily amounts.

5.4 Results

5.4.1 Energy, macronutrient intake and other practices

Average of weekly energy and macronutrient intakes are presented in Table 5.1. Additionally, the athlete reported implementing a weekly refeed day during pre-competition phase aimed to increase EI through elevated CHO consumption to break from consecutive days of energy restriction (Mitchell et al., 2017; Moura et al., 2021). At -4WK (2271 $kcal.day^{-1}$) it consisted of high CHO (6.6 $g.kg^{-1}.day^{-1}$), high protein (2.8 $g.kg^{-1}.day^{-1}$) and low fat content (0.6 $g.kg^{-1}.day$) diet. At -1WK (2100 $kcal.day^{-1}$) the refeed was largely achieved via a lower CHO (4.7 $g.kg^{-1}.day^{-1}$), higher protein intake (3.5 $kg^{-1}.day^{-1}$) and similar fat content (0.6 $g.kg^{-1}.day^{-1}$) than -4WK time-point. No refeed days were incorporated to weekly EI at -2D.

Fluid intake was not prescribed and ad libitum throughout all phases. The athlete revealed engaging in water loading techniques in an attempt to reduce TBW for increased muscle definition (Roberts et al., 2020). In Phase 2, bottled water consumption started at 7.0 L from day 7 (-1WK) to day 4 before competition. It then dropped to 5.0 L on day 3 prior to competition. On the morning of day 2 (-2D), intake further dropped to 3.0 L, and on the day before competition, 0.2 L was consumed. The athlete sipped on water (~0.2 L) and sucked on ice cubes during the day of competition. Fibre and sodium were similar between time-points (*P* >0.05).

Table 5.1: *Average of weekly energy and macronutrient intakes across pre-competition (Phase 1), competition week (Phase 2) and post-competition recovery period (Phase 3).*

	Phase 1	**Phase 2**		**Phase 3**	
	- 4WK	-1WK	-2D	+4WK	+12WK
Absolute energy intake (kcal.day^{-1})	1542 ± 370 (1266 -2271)	1301 ± 416 (927-2100)	1117 ± 96 (1000-1220)	1983 ± 464 (1378-2463)	1976 ± 342 (1575-3251)
Relative energy intake (kcal.kg^{-1}.day^{-1})	29.1 ± 7.0 (24-43)	25.6 ± 8.2 (18-41)	23.1 ± 8.2 (21-25.2)	38.7 ± 9.0 (27-48)	33.7 ± 5.8 (27-56)
Total CHO intake (g.day^{-1})	171 ± 100 (122-348)	106 ± 15 (90-130)	215 ± 105 (101-324)	209 ± 110 (110-377)	180 ± 48 (122-252)
Relative CHO intake (kcal.kg^{-1}.day^{-1})	3.1 ± 1.7 (2.3-6.6)	2.3 ± 1.2 (1.6-4.7)	2.1 ± 0.1 (1.9-2.7)	4.1 ± 1.9 (2.1-7.3)	3.2 ± 0.8 (2.1-4.3)
Total protein intake (g.day^{-1})	118 ±18 (99-148)	134 ± 33 (97-181)	103 ± 7 (91-111)	150 ± 36 (91-198)	151 ± 18 (134-224)
Relative protein intake (kcal.kg^{-1}.day^{-1})	2.2 ± 0.3 (1.9-2.8)	2.6 ± 0.6 (1.9-3.6)	2.1 ± 0.3 (1.9-2.7)	4.1 ± 1.9 (2.1-7.3)	3.2 ± 0.8 (2.1-4.3)

Total fat intake (g.day^{-1})	45 ± 9 (31-56)	34 ± 11 (18-47)	32 ± 7 (25-42)	59 ± 23 (35-91)	69 ± 2 (45-151)
Relative fat intake (kcal.kg^{-1}.day^{-1})	0.8 ± 0.2 (0.6-1.1)	0.7 ± 0.2 (0.4-0.9)	0.7±0.1 (0.5-0.9)	1.1 ± 0.4 (0.7-1.8)	1.2 ± 0.4 (0.8-2.6)

Values in brackets represent ranges of the weekly energy intake.

5.4.2 Nutritional supplements

Alongside the diet dietary logs, the athlete consumed supplements including creatine monohydrate, BCAAs and whey protein; these quantities were considered in the dietary analysis. Athletes also consumed multiple vitamin and mineral supplementation in their diet and also added to the dietary analysis.

5.4.3 Overview of training practices across phases

The data of average daily aerobic and resistance exercise duration, accumulated weekly aerobic and resistance exercise duration, and average daily aerobic and resistance TL, is presented in Table 5.2. The athletes weekly training schedule consisted of six aerobic exercise sessions, and five to six resistance training sessions and one to two rest days totalling 11-13 hours·week^{-1} in Phase 1 and 2 and 7-9 hours·week^{-1} in Phase 3. All aerobic exercise was conducted after an eight hour fasting period using motorised cross-trainer, treadmill, and stair machines. Resistance training was structured into two to three lower body sessions, two upper body sessions and one whole body session in the afternoon hours, concurrently performed in supersets and drop sets.

Table 5.2: *Overview of the self-reported daily/weekly training practices across pre-competition (Phase 1), competition week (Phase 2) and post-competition recovery period*

	Phase 1	**Phase 2**		**Phase 3**	
	- 4WK	-1WK	-2D	+4WK	+12WK
Average daily aerobic exercise duration (min)	65±27	84 ± 13	60±0	28±5	38±36
Accumulated weekly aerobic exercise duration (min)	325	330	240	80	61
#Average daily aerobic training load (AU)	447±198	708 ± 135	N/A	215±50	N/A
Average daily resistance training duration (min)	60 ± 3	91 ± 6	98 ± 15	78 ± 13	96 ± 31
Accumulated weekly resistance training duration (min)	311	450	510	481	388
#Average daily resistance training load (AU)	440 ± 44	587 ± 101	504 ± 136	690 ± 239	580 ± 87

# denotes (RPE x session duration in minutes) to quantify an index of the TL (see section 4.2.5 for information on how this was calculated). N/A denotes the athlete did not note down her RPE for aerobic exercise completed.

5.4.4 Anthropometric Measurements

Changes of BM, sum of 8 skinfold sites (Σ_{8SKf}) and individual skinfold sites are shown in Figure 5.2A, 5.2B and 5.2C, respectively. In Phase 1 (-4WK, Figure 5.2A) the athlete's BM reduced from 53.0 kg to 50.85 kg. Just two days before competing, the athlete weighed in at 48.5 kg (Phase 2). This represents an overall BM reduction of 4.6 kg (8.6%) in the last four weeks pre-competition, including an acute weight loss of 2.4 kg in the final 7-days. In the recovery period, the athlete increased BM by 10.2 kg at +12WK (+19% from -4WK). With regards to skinfold measurement, the athlete reduced Σ_{8SKf} throughout Phase 1 (3.75 mm). This was further reduced throughout Phase 2 (5.5 mm). At 12K post-competition, the athlete increased her Σ_{8SKf} (+35.8 mm) with largest increases observed across abdominal, iliac crest and subscapular skinfold sites. Visual transition of the athlete's body composition is shown in Figure 5.3.

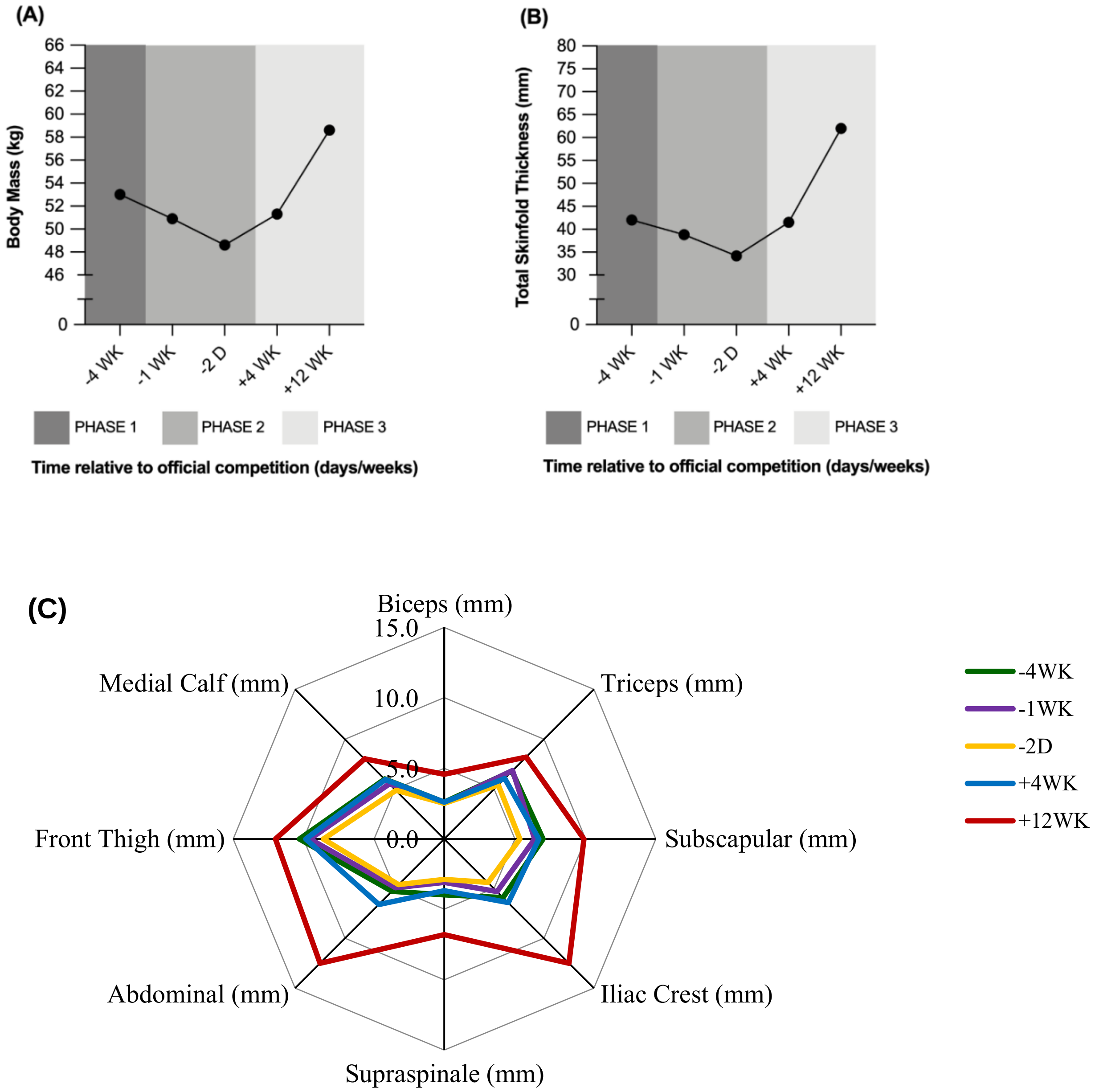

Figure 5.2C—*Changes in Body mass (A), total skinfold thickness of eight sites (B) and individual skinfold sites (biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, front thigh and medical calf (C) across late pre-competition (-4 weeks prior to competition) (Phase 1), competition week (-1 week and -2 days prior to competition) (Phase 2) and recovery phase (+4 weeks and +12 weeks post-competition) (Phase 3). D represents Days and WK represents weeks.*

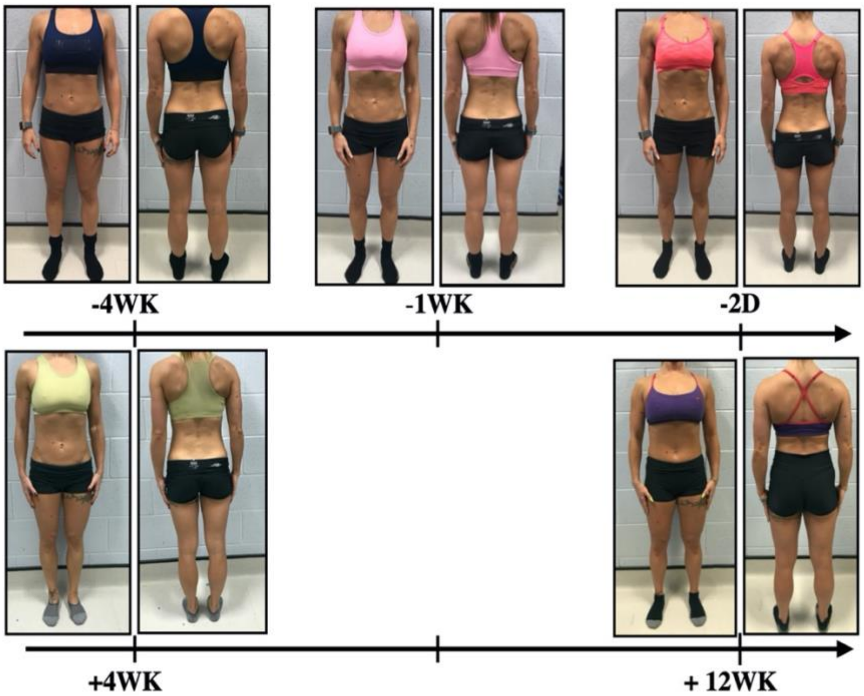

Figure 5.3*—Visual transition of the athlete body composition across late pre-competition (-4 weeks prior to competition) (Phase 1), competition week (-1 week and -2 days prior to competition) (Phase 2) and recovery phase (+4 weeks and +12 weeks post-competition) (Phase 3). D represents Days and WK represents weeks.*

5.4.5 Assessment of resting metabolic rate and ratio

Assessment of RMR is presented in Figure 5.4. There was a decrease of 162 kcal.day^{-1} (11.7%) in Phase 1 to Phase 2 and a further decrease of 99 kcal.day^{-1} (8.1%) at -2D in $RMR_{meas,}$ representing an overall reduction across Phase 1 and 2 of - 261 kcal.day^{-1} (18.8%). These changes are greater than CV% reported for GEM (6.9% shown by Kennedy et al., (2014)) and likely to represent a true change. Regarding RMR_{ratio}, -4WK, -1WK, +4WK and +12WK time-point values remained within an acceptable range (≥ 0.90); however, there was a reduction which was equal to the cut-off value (≤ 0.90) (Strock et al., 2020) at -2D, indicating an acute suppression and potential energy deficiency. The athlete exceeded the -4WK baseline value of RMR_{meas} by Phase 3.

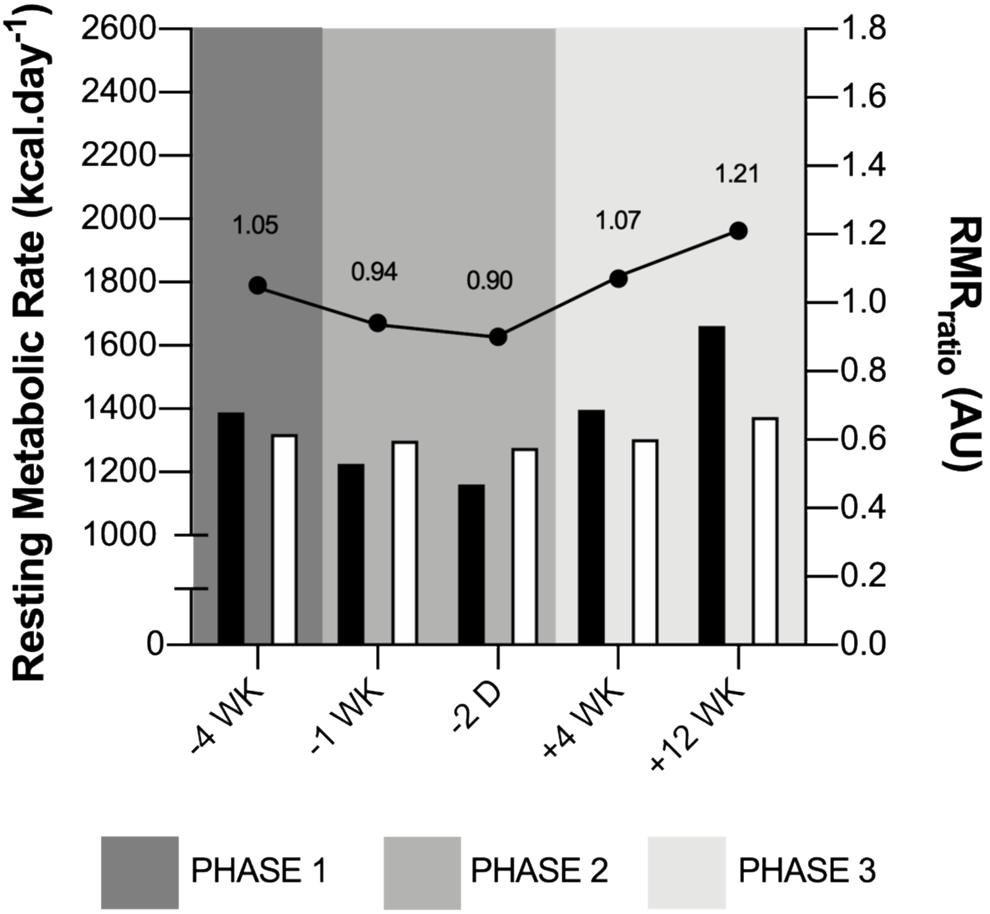

Figure 5.4 *—Changes in resting metabolic rate measurement, prediction and ratio assessments across late pre-competition (Phase 1), competition week (Phase 2) and recovery phase (Phase 3). D represents Days and WK represents weeks.* RMR_{meas} *represents measured assessments of resting metabolic rate,* RMR_{pred} *represents predicted assessments of resting metabolic rate and* RMR_{ratio} *represents the ratio between measured resting metabolic rate and predicted testing metabolic rate.*

5.4.6 Endocrine, micronutrients, lipid profiles, renal and liver function

Blood parameter results are presented in Table 5.3. All micronutrient markers remained within normal values across all time-points, except for Vitamin B12. Vitamin B12 biomarker was higher than the clinical reference value (>771 pg.mL^{-1}) in Phase 1 and 2 but normalised in Phase 3. The plasma lipid profile (total cholesterol, LDL-|C, non-HDL-C and triglycerides) remained within the clinical reference ranges throughout all phases. Fasting insulin and HDL-C were consistent and below reference values across Phase 1 and 2 but substantially increased and decreased above the clinical references ranges (Fasting insulin: 217 pmol. L^{-1} and HDL-C: 1.3 $mmol.L^{-1}$) at +12WK in Phase 3. In addition, the athlete showed increased TG/HDL-C ratio in Phase 3 (1.3), suggestive of an increased risk of insulin resistance. All biochemical markers of renal and liver remained stable throughout measurement points, except urea which remained above clinical normal ranges (>8.04 $mmol.L^{-1}$) at +4WK. In addition, potassium was slightly higher than the expected reference ranges (> 5 $mmol.L^{-1}$) in Phase 1 but remained within the normal ranges in Phase 2 and 3. In general, biomarkers for hydration were within normal ranges across Phases 1 and 2; however, mild hyperhydration (<280 $mOsmol.kg^{-1}$) was evident at -1WK, although sodium concentrations remained below the required threshold (<145 $nmol.L^{-1}$) (Chlíbková et al., 2018). The athlete showed some fluctuations in hypothalamic pituitary ovarian (HPO) hormones which was below the detection level of oestradiol and progesterone in Phase 2. Testosterone concentrations were under detection levels and outside of female age-specific reference ranges (<0.4 $nmol.L^{-1}$) (Haring et al., 2012) in Phase 2 and +12WK time- point. Furthermore, SHBG was slightly lower than the clinical reference range (<18 $nmol.L^{-1}$) at -4WK and -1WK but this normalised in the following time-points. In relation to thyroid hormones, FT4 was within normal ranges across all phases except at -2D which fell below the reference range (< 12 $pmol.L^{-1}$), whereas FT3 was suppressed below reference ranges (< 3. 1 $pmol.L^{-1}$) across all time-points. Muscle damage markers (total CK and CRP) were within reference ranges for the majority of the time points with increased values beyond references ranges at -4WK (>200 $mg.L^{-1}$) and -2D (>5 $mg.L^{-1}$), respectively.

Table 5.3: *Overview of the changes in blood chemistry and hydration across pre-competition, competition week and recovery phase in a competitive experienced international athlete.*

	Phase 1	**Phase 2**		**Phase 3**		**Clinical reference ranges^**
Endocrine function	**-4 WK**	**-1 WK**	**-2 D**	**+4 WK**	**+12 WK**	
Cortisol (nmol.L^{-1})	492	419	528	619*	416	171-618
Testosterone (nmol.L^{-1})	0.3*	<0.3*	<0.3*	0.5	<0.3*	0.34-1.97
IGF-1 (nmol.L^{-1})	21	23	20	29	30	10-38
LH (U.L^{-1})	3.2	<0.7*	0.8*	2.5	7.1	Follicular:2.4-12.6 Ovulation: 14.0-95.6; Luteal: 1.0-11.4
Oestradiol (pmol.L^{-1})	708	<50	<50	494	147	Follicular:72-529; Ovulation: 235-1309; Luteal: 205-786
Progesterone (nmol.L^{-1})	<1	<1	<1	75.4	<1	Follicular: 0.2-2.84; Ovulation: 0.4-38.1; Luteal: 5.8-75.9
FSH (U.L^{-1})	3.4	1.6	3.3	3.3	6.8	Follicular and Luteal: 1.0-9.0
SHBG (nmol.L^{-1})	17*	15*	20	110	18	18-114
Free T4 (pmol.L^{-1})	18.2	12.1	11.5*	13.2	12.5	12-22
Free T3 (pmol.L^{-1})	2.9*	2.7*	2.8*	2.6*	3.0*	3.1-6.8
Prolactin (mU.L^{-1})	17	15	20	110	18	<700
Insulin (pmol.L^{-1})	<21	30	35	25	217*	17.8-173
Renal and liver function						

U_{sg} (g.mL^{-1})	1012	1007	1021*	-	-	1.001-1.020
U_{Osm} (mOsmol.kg^{-1})	369.5	214*	627	-	-	280-700
Sodium (mmol.L^{-1})	141	141	142	137	139	135-145
Potassium (mmol.L^{-1})	5.6*	4.1	4.6	4.3	4.4	3.5-5.1
Urea (mmol.L^{-1})	5.5	3.5	7.9	9.1*	7.9	2.76-8.07
Creatinine (µmol.L^{-1})	71	64	67	52	52	45-84
Albumin (g.L^{-1})	48	47	48	44	44	66-87
Globulin (g.L^{-1})	24	24	26	24	22	20-39
Total Protein (g.L^{-1})	72	71	74	68	66	66-87
Alkaline Phosphate (U.L^{-1})	36	35	38	37	43	35-104
Alanine transferase (U.L^{-1})	39*	32	27	21	28	<33
Lipids and Lipoproteins						
Total Cholesterol (mmol.L^{-1})	3.6	3.1	2.9	4.1	3.7	<5.2
TG (mmol.L^{-1})	0.4	0.4	0.4	1.3	1.3	<1.7
LDL-C (mmol.L^{-1})	2.2	1.7	1.3	1.7	2.1	<3.0
HDL-C (mmol.L^{-1})	2.2	1.7	2.3	1.7	1.3*	<1.15 high risk; 1.15-1.68 moderate risk; >1.68 low risk

CHOL/HDL	0.2	1.8	1.3	2.4	2.8	<3.0
Non-HDL (mmol.L^{-1})	3	2.6	2.1	2.3	3.7	<4
TG/HDL-C ratio	0.3	0.3	0.29	0.72	1.3	>3: Significant risk of heart attack and stroke
Micronutrients						
Serum total 25(OH)D (mmol.L^{-1})	75	82	77	63	63	>50 adequate
Vitamin B12 (pg.mL^{-1})	859*	902*	1058*	718	662	197.0-771.0
Iron (μmol.L^{-1})	19.8	13.4	10	17.7	10.7	5.8-34.5
Iron saturation (%)	28	17	14	26	14	<50
Ferritin (ug.L^{-1})	30	21	46	28	15	13.0-150.0
Transferrin (g.L^{-1})	3.1	3.4	3.2	2.95	3.39	2.0-3.6
Folate (ug.L^{-1})	>20*	14.7	12.3	10	11.2	1.5-20
Magnesium (mml.L^{-1})	0.84	0.79	0.8	0.83	0.76	0.66-1.07
Chloride (mml.L^{-1})	100	100	102	100	101	98.0-107.0
Bicarbonate (mml.L^{-1})	28	24	25	23	24	22-29
Adjusted Calcium (mmol.L^{-1})	2.42	2.27	2.33	2.27	2.32	2.2-2.6
Muscle damage and inflammation						

Total Creatine Kinase ($mg.L^{-1}$)	208*	168	187	110	154	26.0-192.0
C-reactive protein ($mg.L^{-1}$)	<5	<5	23*	<5	<5	<5.0

* denotes any values that fall outside of the clinical reference range. U_{usg} indicates urine specific gravity; U_{osm} indicates urine osmolality; LH indicates luteinizing hormone; FSH indicates follicle-stimulating hormone; SHBG indicates sex hormone binding globulin; IGF-1 indicates Insulin-Like Growth Factor; LDL-C indicates low density lipoprotein cholesterol; HDL indicates high density lipoprotein cholesterol; Serum total 25(OH)D indicates total 25 Hydroxy-Vitamin D (25(OH)$D_{2,3}$); TRG indicates triglycerides. ^Clinical reference values were provided in the kit insert documents from Liverpool Royal Hospital, Department of Clinical Biochemistry and Metabolic Medicine. Where reference values were not specified within the documents, the clinical biochemistry reference values were taken from the NHS Foundation Trust UK website.

5.4.7 Menstrual cycle, oral contraception use, and risk of low energy availability questionnaires

At the -4WK time point, the athlete reported using a non-hormonal copper coil for three years and 6 months and presented with irregular menses (last day 1 bleeding occurred 7 weeks ago prior to the -4WK measured time point) with a bleeding of five days a week after -4WK measured time point. In Phase 3, the athlete reported two days of light bleeding a week after +4WK measured time point. Therefore, it is considered that she may have been in a state of oligomenorrhea (Menses length >35 days, (Elliott-Sale et al., 2021), which did not normalise by Phase 3.

Total LEAF-Q score for the athlete was 17 points (0 points from injuries, 9 points from gastrointestinal function, and 7 points from menstrual cycle) in Phase 1, 16 points (0 points from injuries, 8 points from gastrointestinal function and 7 points from menstrual cycle) in Phase 2 and 7 points (0 points from injuries, 0 from gastrointestinal function and 7 points from menstrual cycle) in Phase 3.

5.4.8 Mood and sleep assessment:

Mood and sleep assessment results are presented in Table 5.4. There were psychological fluctuations in BRUMS scores across the time phases with increases in tension, depression and anger and reductions in vigour from Phase 1 to Phase 2. Consequently, this resulted in elevated TMD beyond normative values for athletic populations (>24 AU) (van Wijk et al., 2013) at -1WK, -2D and +12WK time-points. However, the BRUMS score returned to below the threshold (TMD <20 AU) at +4WK but reversed back to higher values (TMD = 30 AU) accounted for by increases in fatigue and depression at +12WK. PSQI scores remained higher than the threshold (> 8AU) at all time points apart from +4WK.

Table 5.4: *Changes in mood subscales, total mood disturbance (TMD) scores and sleep quality (PSQI scores) throughout the pre- during and post-competitive phases*

	Phase 1	**Phase 2**		**Phase 3**	
	-4 WK	**-1WK**	**-2D**	**+4WK**	**+12WK**
Tension (AU)	2	7	8	3	4
Depression (AU)	3	8	7	2	8
Anger (AU)	4	8	6	1	2
Vigour (AU)	2	4	0	5	4
Fatigue (AU)	12	12	12	4	12
Confusion (AU)	2	0	2	0	0
TMD Scores (AU)	15	39	35	15	30
PSQI Scores (AU)	12	12	15	7	11

TMD= Total Mood Disturbance scores, PSQI = Pittsburgh Sleep Questionnaire Index, WK= Week, D= Day, AU = arbitrary unit.

5.4.9 <u>Competition results</u>

The athlete won a silver medal at the IFBB professional qualifiers (Romania Muscle Fest 2018), after successfully qualifying to the final comparison round against 26 athletes. As such the athlete did not obtain her professional status or receive the qualification to the Olympia championships.

5.5 Discussion

This case study aimed to examine the dietary intakes, anthropometric profiles and resultant psychophysiological responses across different phases of a competition season (late pre-competition, competition week and recovery phase) in an experienced Bikini Fitness athlete competing for her professional status at an international competition. The main finding showed that in the recovery phase (Phase 3), the athlete substantially increased EI (when compared to -2D) along with increases in BM (+19%), Σ_{8SKf} (+28 mm), as well as elevated levels of fasting insulin and cardiometabolic markers (fasting insulin and TG/HDL-C ratio), indicating a hyperphagia response. Furthermore, symptoms of RED-S were likely present in Phases 1 and, as evidenced by suppressed RMR_{ratio} and endocrine markers including FT3 and FT4, oestradiol and testosterone with self-reported oligomenorrhea and TMD above cut-off value); some of which did not return to clinical reference values following 12 weeks of refeeding (*i.e.,* FT3 and testosterone). These findings offer practitioners and athletes detailed insights into the shifts in subjective and objective health markers during training and recovery following a physique competition.

Although a true baseline was not measured, the athlete might have experienced rebound hyperphagia (19% increase in BM at +12WK) with absolute EI values ranging 1575-3251 kcal.day^{-1} (27-56 kcal.kg^{-1}.day^{-1}). Such response has been reported to be caused by autoregulatory feedback signals between fat and FFM tissue and appetite control, memory of energy portioning and adaptive thermogenesis (Dulloo et al., 1997). There was likely a real increase (28.6% and 13.2% compared to -2D and +4K, respectively) in athletes measured RMR_{ratio}

(1.21) with an increased value of TG/HDL-C ratio, decreased value of HDL-C and a sign of hyperinsulinemia at +12WK. Although the results suggest an increased risk of insulin resistance, the athlete may have been experiencing overcompensation (Dulloo et al., 2015) which may normalise over time. Similar findings are also observed in previous survey and laboratory-based studies in both female and male physique athletes (Andersen et al., 1994; Longstrom et al., 2020 and Trexler et al., 2017) and may explain the binge eating behaviours and weight regain also seen in Chapter 3 (Study 1). Furthermore, this may contribute to the observational work on weight cycling in individual combat sport athletes (Morehen et al., 2021; Kasper et al., 2018). However, rebound hyperphagia is of particular concern considering the cardiometabolic and obesity risk factors documented in later life among athletes who 'weight cycle' (Miles-Chan & Isacco, 2020; Saarni et al., 2006) (See section 2.12.7). Additionally, there is a risk for disturbed body image and DE/ED associated with gaining BM during such (eating) transitions (Helms et al., 2019). Future research should interview FP athletes to gain richer understanding of their lived experiences and perceptions of changing their BM during their sporting career.

The athlete showed a slow weight loss approach (~0.7 $kg.week^{-1}$) in Phase 1, whilst Phase 2 showed a more rapid weight loss approach (2.4 $kg.week^{-1}$). Specifically, three weeks of energy restriction (equating to average daily EI values: 29.1 $kcal.kg^{-1}.day^{-1}$) alongside weekly average resistance training (60 ± 3 min) and aerobic exercise (65 ± 27 min) routines, resulted in a decrease in BM (- 4%) and $\Sigma 8SKf$ (-3.75 mm) in Phase 1. A further reduction in BM (-4.7%) and $\Sigma 8SKf$ (-4.6 mm) was achieved in Phase 2 with a reduced EI (23.1 ± 8.2 $kcal.kg.^{-1}.day^{-1}$). Despite it was not possible to confirm LEA in this report, the athlete may have presented with symptoms of RED-S consequences in Phase 2.

Reproductive hormones, oestradiol and progesterone fell below detectable levels in Phase 2, with prolactin reaching its lowest point compared to other phases. All returned to clinical reference levels at +4WK. It is biologically plausible that the data reflects a potential decline in energy availability over time, as competition approaches. This might explain the observed suppression of the reproductive axis, leading to a decrease in oestradiol levels from 708 pmol.L^{-1} to levels below the detectable limit. In the four weeks post-competition (+4WK), with refeeding, a rebound of these values might have occurred as the system is reinstated (Loucks and Verdun, 1998).

To recall, the HPO is the most important system for regulating female reproductive endocrine function (Xie et al., 2021), while the hypothalamic- pituitary-thyroid (HPT) determines the set point of thyroid hormone production (Ortiga-Carvalho et al., 2016). Observations of suppressed testosterone, FT3, acute FT4 and RMR_{ratio} combined with self-reported oligomenorrhea were observed in Phases 1 and 2. Most of these adaptations have been consistently shown to respond to acute and chronic LEA and linked to suppression of neuroendocrine axes such as HPO and HPT (Areta et al., 2021). However, the present study demonstrated that despite 12 weeks of refeeding (via increased EI and high protein intake of 2.7-2.9 g.kg.day^{-1} with +19% increase in BM), there was still persistent menstrual irregularities accompanied by incomplete recovery of endocrine hormones including testosterone and FT3. Previous studies (Arends et al., 2012; Cialdella-Kam et al., 2014;

Lagowska et al., 2014a; Lagowska et al., 2014b; Mallinson et al., 2022; De Souza et al., 2021) demonstrate that increasing energy availability can restore menses in hypothalamic oligo-amenorrheic exercising females with BM gains ranging between 1 - 5.3kg (De Souza et al., 2021). However, this process could take more than 12 months and may be associated with baseline energetic status such as FM (through the effects of leptin) and the increased volume of EI (De Souza et al., 2021; Mallinson et al., 2022).

The athlete showed sustained testosterone concentrations below detection levels throughout the study period (≤0.3 nmol.L^{-1}). Past studies assessing testosterone levels in females with LEA surrogates have yielded conflicting outcomes (Elliott-Sale et al., 2018). Some indicate lower testosterone in amenorrhoeic athletes compared to eumenorrheic counterparts (Christo et al., 2008) and anorectic females (Miller et al., 2007), while others show elevations in females with menstrual irregularities (Rickenlund et al., 2003). Nonetheless, the present study represents a time-course analysis spanning a 4-month period, differing from cross-sectional studies (Christo et al., 2008; Miller et al., 2007; Rickenlund et al., 2003). Consequently, the influence of energy restriction on testosterone concentrations in physique athletes remains uncertain and warrants further investigation, potentially through longer study designs encompassing time points beyond +12WK. This understanding is crucial for tailoring post-competition nutrition and training practices to individual athletes. Although suppressed $RMR_{ratio,}$ (≤0.90) (Staal et al., 2018) could be caused by an energy deficiency (Strock et al., 2020), it is speculated that down-regulation of leptin (Park & Ahima, 2015) from food deprivation may have partially modulated the HTP and HPO axes causing such responses in FT3 and testosterone blood markers. Nevertheless, sustained low FT3 and oligomenorrhea are not exclusively caused by LEA, and therefore we cannot rule out any underlying medical issues (*i.e.*, hypothyroidism or polycystic ovary syndrome) in the present case study.

As expected, on evidence from study 1 and previous prevalence data (Chappell et al., 2018), the athlete conducted a water loading protocol for the purpose of reducing TBW content which induced no clinical meaningful changes to blood biochemistry such as plasma sodium (despite a mild overhydration value at -1WK via urine osmolality). It is difficult to decipher the exact contribution of water loading and/or energy restriction to the 2.4 kg BM loss. Nevertheless, the athlete's water loading protocol appears to agree with a previous study on male combat sport athletes, which found no changes to U+E blood markers from acute BM loss (2.4%) when compared with a match control group (Reale et al., 2018). While urea, an indicator of protein oxidation, surpassed the reference range (>8.1 $mmol.L^{-1}$) at +4WK time point, it returned to normal levels by +12WK. This increase may reflect the high intakes of proteins (~ 4 $g.kg^{-2}.day^{-1}$ self-reported in the diet records (Martin et al., 2006). However, to draw conclusions about the efficacy and safety of water loading protocol, further research should observe its physiological effects in a larger sample of females under free-living and laboratory conditions.

Maintaining a large energy deficit, acutely or chronically can be psychologically challenging (Newton et al., 1993; Rohrig et al., 2017). The athlete showed elevated mood disturbance in Phase 2 (derived from highest scores of tension, fatigue and lowest vigour scores) compared to Phase 1. Even with an acute refeed day (consuming 4.7 $g.kg.day^{-1}$ of CHO at -1WK compared to 1.6-2.5 $g.kg.day^{-1}$ on the other days at -1WK), mood state was positively affected, consistent with findings in males (de Moraes et al., 2019; Finn et al., 2004). At +12WK, TMD exceeded the threshold, primarily due to increases in depression and fatigue subscales (compared to +4WK). At +12WK, TMD exceeded the threshold, mainly due to increased depression and fatigue subscales (compared to +4WK). Prior studies have reported depression symptoms during post-competition weight regain in FP athletes (Mathisen & Sundgot-Borgen, 2019b; Anderson et al., 1994). However, for this study, it remains speculative due to the absence of baseline pre-competition mood state observations. Future research in this area should assess the effects of refeeding following energy restriction on mood states over a prolonged period (> 3 months), controlling for diet (*i.e.,* provide the athletes with the diet) and using a cross-over research study design.

Self-reported poor sleeping quality in the FP athlete (as indicated by high PSQI total scores) was experienced throughout Phase 1 and 2 with an expected improvement at +4WK. This contrasts with previous findings in FP athletes and supports a case report in male bodybuilding (Pardue et al., 2017; Longstrom et al., 2020). The inter-variability of subjective sleep patterns may be attributed to individualised factors such as training volume and schedules, energy intakes and lifestyle (Walsh et al., 2021). It has been shown that CRP, a marker of acute inflammatory system, increases during disturbed or insufficient sleeping patterns (Meier, et al., 2004). It has been shown that CRP, a marker of acute inflammatory system, increases in response to disturbed or insufficient sleeping patterns (Meier, et al., 2004).

CRP levels spiked beyond reference values at -2D (23 mg.L^{-1}). However, it is important to note that basal inflammation levels vary widely among individuals, influenced by factors such as stress and activity levels leading up to the blood sample collection (Mullington et al., 2010). Consequently, it remains uncertain whether this increase was a result of sleep deprivation (Meier et al., 2004), the exercise from the preceding day, or stress related to the physique competition approaching at this time point (Kasapis and Thompson 2005). More research, incorporating both objective and subjective measures to assess chronic sleep disturbances in weight-restricted athletes (Nedelec et al., 2018) is crucial to prevent impaired recovery and resistance training performance due to inadequate sleep.

5.5.1 Limitations

The participant had commenced her pre-competition phase before the -4WK measurement time point. Therefore, this time point (-4WK) does not reflect a true baseline and as such her dataset does not include the total change from baseline to competition day or baseline to recovery. The absence of a true baseline time point is attributed to the athlete's late decision regarding the exact competition date during the dieting process. Second, body composition (*i.e.*, FFM, FM and bone mineral content) was not assessed using DXA. Due to lack of FFM measures, it should also be acknowledged that RMR_{ratio} values should be interpreted with caution given the potential for significant underestimation of RMR_{pred} when using BM-equations (Schofield et al., 2019). It is however worth noting that using DXA can be prone to errors when researching FP athletes, as they often manipulate carbohydrate, salt, and fluid intake leading into competition. Previous work has shown that glycogen loading following a glycogen-depleted exercise protocol can lead to substantial increases in estimates of FFM (3% and 2%) and TBW (2.3%) (Bone et al., 2017). Furthermore, to quantify EEE for a specific resistance training session remains difficult using wearable physical activity monitors, as such an estimation of EA was not achieved. To increase understanding of the exercise activity levels in physique athletes, future research may consider utilising the newer wearable technology such as WHOOP band or Oura ring activity trackers. In addition, it should be acknowledged that the athlete missed reporting the details of the "weights" (in kg) during resistance training sessions and therefore calculation of training volume (sets x reps x weights) was not possible either. Future studies should also inquire about the use of refeed days in non-collection weeks (*i.e.,* in the present study being 3WK and 2WK before competition) to give valuable insights into athletes' typical dietary strategies in the pre-competition phase. Lastly, the case study is only indicative of a single participant and therefore cannot immediately extrapolate to wider populations, but it does provide meaningful data which allows a greater understanding of individual experiences. Accordingly, this allows practitioners to recognise the need to provide more individualised support (Burden et al., 2021).

5.6 Conclusion

In summary, this case report highlights that an FP athlete attempting to gain professional status showed extreme weight fluctuation within a period of four months with increased risk of insulin resistance and likely negative symptoms of RED-S consequences. The study adds to the growing literature that an athlete who is highly experienced and competes in a division with lower requirements for muscularity and leanness compared to other divisions can also be at risk of long-term physiological and psychological health implications. Whilst the data may prompt critical reflection of the potential health consequences associated with different phases of the competitive season, future research should employ a qualitative paradigm to gain an in-depth understanding of athletes lived experienced from various divisions and experience levels. This will allow a complete understanding of the antecedents and consequences across athletes' careers and inform interventions to improve athletes' health and welfare.

[redacted]6. Living on a Rollercoaster: A Qualitative Method Exploring the Lived Experiences of Female Physique Athletes' Sporting Career

6.1 Introduction

While the literature corpus remains largely focussed on the practices of the FP athletes, and this is useful to inform an understanding of the biological effects of participation, there is a lack of consideration of the psychological and social dimensions of FP athletes' experiences (Suffolk et al., 2013). More broadly, the underrepresentation of women's voices across sports science research also extends to the lived experiences of women's participation in physique sports and therefore it remains unclear how FP athletes experience their sport. With such partial understanding, researchers and practitioners may not have a fully humanised view of what it means to be a FP athlete. This is remiss because FP athletes have been identified as particularly vulnerable due to the combination of high–risk behaviours *(i.e.,* low EI combined with increased training duration and load for prolonged periods, and use of competition week strategies identified in chapter 3, 4 and 5) and social disapproval (i.e., stigmatised female embodiment of masculine and muscular physiques) (Aspridis et al., 2014).

In Chapter 5, a case report showed an FP athlete dedicating increased time to resistance and aerobic training and reduced EI compared to the post-competition period. Consequently, the athlete experienced BM overshoot and potential associated physiological and psychological health implications in the post-competition phase, some of which were not fully recovered after 12 weeks of recovery.

FP athletes' bodies are likely to undergo significant transitions between season phases in their quest for high levels of muscularity, low FM and symmetry (Alwan et al., 2019; Chapter 5). As such, these athletes exemplify a disciplined transformation of the body in action, that is prompted by dietary practices and physical training (Sparkes et al., 2005).

The social, psychological and emotional outcomes from participation in physique sports can be diverse (Aspridis et al., 2014). Engaging in physique sport can generate a social and supportive community (Roussel & Griffet, 2000), feelings of empowerment, increased self-confidence (Probert et al., 2007), positive body image (Walters & Hefferon, 2020) and long-term involvement in exercise behaviours (Sparkes et al., 2005). Thus, the current literature implies that from a participant perspective, participation in competitive physique sports may be viewed as a positive experience for many women.

Despite these positive benefits, many FP athletes encounter negative reactions from the society towards their intense dieting and training regime during their body transformation (Chananie-Hill et al., 2012; Suffolk et al., 2013). Athletes can experience stigma for their 'deviant' identities (e.g., drive for hypermuscularity combined with low FM, anorexic/bulimic behaviours and exercise dependence) (Smith and Hale 2004; Hale et al., 2013 and Chananie-Hill et al., 2012). In most mainstream Western societies, athletes engaging in these behaviours maybe seen as violating everyday social norms (Probert et al., 2007; Shilling & Bunsell, 2009; Suffolk et al., 2013). Accordingly, athletes may experience judgements and stigma from others in their daily activities.

Additionally, evidence suggests that physique athletes may also experience mild or severe health consequences (Probert et al., 2007) during their pursuit of the aesthetic ideal such as oligo/amenorrhea, suppressed RMR and negative mood profiles (Mathisen et al., 2019; Hulmi et al., 2016; Chapter 4) Consequently, the FP athletes not only risk social stigma, but could also experience a psychophysiological risk of partaking in this sport (Worthen & Baker, 2016). The negative effects of physique sports could also extend to post-competition, with instances of depression, weight regain, adverse alterations in clinical metabolic and endocrine parameters and risk of ED (Andersen et al., 1998; Mathisen & Sundgot-Borgen, 2019; Whitehead et al., 2020; Chapter 4) as they transit into off-season/recovery body and often dislike this appearance (Helms et al., 2019). There is also data from Chapter 3 which shows that approximately 42% out of 158 FP athletes engage in two PWCM to manage their weight, which may transit into chronic abnormal eating behaviours. While there may be positive outcomes from participating in physique sports, there is also evidence that the practices used to achieve sporting success can be precarious and associated with maladaptive outcomes.

To better support FP athletes throughout their sporting career, practitioners need to understand them, their temporal experiences, and the social contexts they inhabit. The current literature does not provide a clear understanding of women's initiation into the sport and how it influences their emotions, thoughts, and perspectives across different seasonal phases. Given this lack of insight, this research aims to make an original contribution to the literature by valuing FP athletes voices (Kitching et al., 2020), and to describe the complex, temporal and subjective experiences of being a competitive FP sport athlete in the UK. As such, the purpose of the study was to explore personal in-depth lived experiences of FP athletes across competitive season phases.

6.2 Methods

6.2.1 Philosophy

This study is underpinned by an interpretivist philosophical perspective. This asserts multiple realities among individuals and recognises that individual experiences are relative, unpredictable and influenced by multiple external and internal factors (Smith & McGannon, 2018). As such, the study aimed to report and interpret the subjective and individual unique experiences of UK-based FP athletes, from the lead researcher's subjective perspective.

6.2.2 Participants

Ten Caucasian, FP athletes (age 28 ± 4 years (range: 21 – 35) from Northwest and East England participated in the study. On average, participants had three years (range: 1-6 years) of competing experience in United Kingdom Anti-doping affiliated physique organisations. Participants were recruited through a purposeful sampling strategy using gatekeepers (*i.e.*, gym managers), social media platform groups and the network of the principal investigator. A 'snowball' recruitment technique was implemented, wherein key informants were asked if they knew of others who may be interested in the study (Naderifar et al., 2017). A FP athlete participant was defined as being aged 18 or older, had competed within the past two competitive seasons and had more than two years of competition experience and never engaged with image and performance-enhancing drugs. At the time of interviews, all participants were in the post-competition or off-season period. The lead researcher established trust through training sessions and meetings with athletes before data collection, ensuring open-minded and honest participation in the study. This allows the researcher to become an ‘insider’ (Yilmaz et al., 2013) (*i.e.*, allowed the researcher to see what was going on, and not just to hear).

6.2.3 Data Collection

Semi-structured interviews were carried out separately with each participant. This method was deemed appropriate to allow the interviewee a degree of flexibility to record their own thoughts and feelings in depth with relatively little restriction, whilst also providing the interviewer with a deeper knowledge about their experiences (Sparkes, 2013). All interviews were conducted by the principal researcher who drew upon their experience of being a former athlete, however experiences were not influential to the discussions and they were merely used to building confidence and a rapport with the athletes. In addition, this helped the researcher to connect with the FP athletes and understand their common terminologies and language used in the sport. Ten interviews took place in a private room at the university to ensure confidentiality. All interviews were audio recorded and ranged in length between 63 minutes and 91 minutes (mean = 68.96 min, SD = 12.10 min). Interviews were transcribed verbatim by the lead researcher into separate Microsoft Office Home (Redmond, WA, USA) documents and imported into QSR NVivo 10 software package (QSR International, Version 12, Victoria, Australia), prior to data analysis. All interviews took place between June and September 2018.

An interview guide was implemented to provide participants an opportunity to share their experiences using open-ended and neutral questions to accommodate the purpose of enabling athletes to share their experiences and allow flexibility. The interview guide was divided into six sections (their participation in the sport (*i.e.*, background and motivations), self-identity, experiences and dietary and training practices in the pre-competition phase and off-season phase, and the perceived psychological and physiological health concerns) with four open-ended questions assigned to each section (e.g., *How would you describe the major differences in your body now as a physique athlete and the body you had before? In the weeks leading up to competition (pre-competition phase), can you take me through the whole process?).* The interview guide was developed based on studies investigating athletic identity in other aesthetic and weight-sensitive sports (Kerr et al., 2006; D. Martin et al., 2017). Readers are directed to the appendix 9.9 (Chapter 9) for a complete copy of the interview guide. A theorist in the area of qualitative research (blinded) reviewed the questions to permit refinement and development of the research instrument. Prior to the interviews, the interview guide was piloted with two participants; a retired physique athlete who did not participate in the larger study, and a researcher in the qualitative field of female bodybuilding, unrelated to this study. The draft interview guide was slightly modified to incorporate the feedback from the pilot interviews. During interviews, subsequent probing occurred to clarify or elaborate responses and gain a deeper understanding of each participant's story (Sparkes, 2013).

Saturation, a methodological concept involving collecting data from participants until repeated patterns are observed (little or no new information is received), was used in the present study to ensure credible accounts (Saunders et al., 2018). While some researchers argue against data saturation (Braun and Clarke 2021), others report the need to reach saturation point to provide credibility (Morse 2015; Guest et al., 2006; Smith 2017). In this study, the sample size reached what was considered a saturation point. After interviewing the ninth participant and obtaining similar results, we proceeded to interview the 10th participant to ensure that there was no more new information. The 10th participant shared similar experiences, confirming the data was saturated. As Smith (2018) explains, qualitative research does not seek to generalise to a wider population, rather it seeks to provide in-depth insights into the specific experiences of participants recruited.

6.2.4 Ethics

The study gained ethical approval from Liverpool John Moores University ethics committee (18/SLM/009). As advised by the committee, athletes (n=4) showing signs of mental and/ or physical vulnerability were signposted to *Beat Eating Disorder* charity (https://www.beateatingdisorders.org.uk/). In the interest of anonymity, pseudonyms (a common practice of allocating false names (Allen & Wiles, 2016)) were assigned to the findings. Participants were informed of their right to withdraw from the study at any time. Informed consent was obtained prior to any interviews.

6.2.5 Data analysis

Data analysis drew on thematic analysis (TA) based on a six-step process (Braun & Clarke, 2006; Clarke & Braun, 2013). Thematic analysis aims to interpret and analyse patterns (themes) within the data, produced at the intersection of the researchers theoretical assumptions, and report results that are relatively understandable to the general public (Braun & Clarke, 2019). This framework was selected based on its flexible application to elicit a rich thematic description and interpretation (Clarke & Braun, 2013). First, immersion was achieved by re-reading each transcription allowing the researcher to become familiarised with the data and for meanings and general themes to be noted. Second, initial coding took place on each transcript where the researcher examined any relevant content across the participants data set, whilst keeping the research question at the forefront (Gale et al., 2013). During this stage, some individual codes were combined to generate a general theme, whilst those considered irrelevant to the research questions were omitted. Thereby, each theme was named and defined to clearly identify the essence of what each theme was about and why it was interesting (Sparkes, 2013). Each stage was illustrated with a direct quotation in an attempt to capture the perceptions and experiences of participants. Confirmation bias is a possibility but to minimise this, the study has implemented *critical friend*, 'insider' relationship to the participants, open-ended and neutral questions in the interview guide and member reflections in the process post-analysis (see section 6.2.6).

6.2.6 Rigour

To ensure rigour, firstly, during the analysis, a *critical friend* was recruited with the purpose of critically considering researcher subjectivity (Smith & McGannon, 2018). The 'critical friend' met with the researcher regularly to provide critical feedback on the emerging results and explore opportunities for the inclusion of alternative experiences. Furthermore, the research team checked and challenged the first authors interpretation of the data, so their prior experiences added value and were not tainted to data analysis. Thirdly, member checks of the transcriptions and overall main findings were conducted through email and voice recordings. Some of the comments made included: *"You have literally described the five years of my life, so I would agree that is a very good understanding of the momentum we are* *in, before during and after"* (Amelia) and *"I think your interpretation is absolutely spot on. It's definitely a rollercoaster, in all honesty there was absolutely no post-competition support at all* (Lisa). Member reflections were also undertaken which gave the participants opportunities to provide additional information on the data and to consider whether the emergent model of themes and the interpretation were accurate and fair. Participants were asked to reflect and explore any gaps in the results or similarities concerning interpretations of the general themes once they had done member checking. This ensured confirmation bias was minimised from the study and the findings are credible and research valid (Smith and McGannon 2018). The lead researcher also kept a reflective journal throughout the data collection and analysis to identify personal observations and assumptions that may affect the analysis. The reader should note that the data was interpreted from a relativist epistemology when establishing the trustworthiness of the work, and as such this means there is no universal valid or reliable truth, but the truth is multiple, shaped and mind-dependent (Smith et al., 2016). From this position, the methodology enabled the researcher to rigorously explore a range of lived experiences of FP athletes.

6.3 Results and Discussion

The central theme of this study was a 'dynamic physical, psychological and social rollercoaster experience'. The metaphor of a rollercoaster is apt because it represents temporal moments including the initial choice to engage, a slow arduous and fearful climb, a brief moment at the zenith when everything is in view, before a fast descent and return to the foot of another climb. This description resonates with the experiences of FP athletes as detailed in the thematic map (Figure 6.1) and the five stages that follow: 1) *Starting the journey, 2) Body changes, 3) Public success with private isolation*, 4) *Physical and psychological tension* and 5) *Aftercare*. By including this map (not a graph), it was attempted to visually represent and connect these themes to readers.

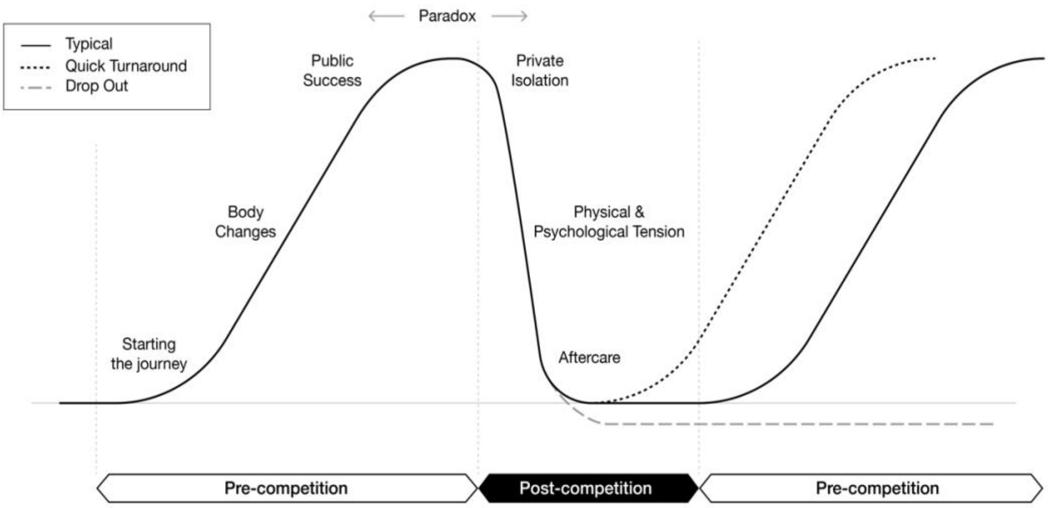

Figure 6.1*—A visual model (image) of the female physique athlete's experiences from the start of dieting to competition and the return to baseline before the start of diet and training again, representing the outcomes of the present study (not priori hypotheses) and the overall theme of a dynamic physical psychological and social rollercoaster. The timeline represents themes to competition/recovery. The small dotted line moving upwards explains the athletes who reported returning to dieting soon after the previous competition. The black line moving upwards explains the athletes who reported to have a long-term break/recovery time before their next competition. The dotted line moving horizontally explains the athletes who reported quitting the sport after their first* competition*. This has been put in to understand, represent and connect themes and illustrate the journey these participants go on.*

6.3.1 <u>Theme 1: Starting the journey</u>

Starting the journey refers to how participants enter physique sports and their past feelings related to their previous identities. Just like a rollercoaster, typical journeys began with anticipation, but also a slow controlled climb towards a peak of the body ideal. This climb is prompted by various motivations. Mimicry emerged as a strong influencing factor. Six participants reported that they became interested in physique sports because they saw lean women who conveyed a public picture of themselves on social media (Instagram platform), which made them attracted to the particular type of look displayed in the digital pictures.

> *"And I think that kind of attracted me, you want to be that person, you want that person to look and think of you like 'wow look at her, I want to be like her, I wanna do that sort of thing'" (Jenna)*

> *Literally, because I followed a lot of fitness Instagram accounts, and there were certain ones where they were bikini competitors, and so it was watching the process. They'd started like say 12 weeks out, some would do 6 weeks out, and it was interesting watching them each week diet down and get leaner and just spot interested me and I was like 'I want to do something like that' (Katie)*

On Instagram, a social media platform, the use of 'fit inspiration' hashtags indicates a shift among women, moving away from the 'thin-ideal' and embracing the 'fit-ideal' (Tiggeman and Zaccardo 2018) with over 28 million images tagged under 'fitspiration' and 'fitspo' hashtags (Tiggeman and Zaccardo 2018). It is possible that the shift in body image ideals may have contributed to an increased interest and participation of women in physique sports (Alberga et al., 2018).

Likewise, two participants desired to resemble someone else they had seen in person, not just through social media. They were inspired to take their muscularity and fitness to a higher level. For instance, Nina and Kerry state:

> *"I started training in a private gym and everyone was, well all the women there were going in for competitions, so it was like 'well I like the look of this'. So, then I started just resistance training with them and then once they were close to shows, I was like 'I want to do one!"* (Nina)

> *"I saw those girls on stage. I thought 'wow I want to be like that, and I wanna push my body to that point and I wanna be on stage and look like that"* (Kerry)

The importance of imitation in human behaviour, has been noted by other qualitative work (Strand, 2018) using the term *mimesis*, with the argument that human desire may be mimetic. For example, humans experience desire based on seeing other people's success, rather than based on intrinsic values as it is seen to grant greater success (Strand, 2018). Indeed, as the females engage with physique sports they are judged through comparison with others. However, the data suggest that comparisons with others are not only a method of judging but may be the motive that starts the competitive journey. A previous study (Parish et al., 2010) supported this notion and reported that *emulation*, a form of idolisation of an ideal, which can also include aspiration to expectant social norms, was the most common reason among sixty-three female bodybuilders. Thus, for these women, the decision to ‘get on board’ the rollercoaster was influenced by seeing those at the top.

Mimicry was not always the case for all FP athletes. For Julie, a history of a broken relationship was the reason to start weightlifting and participating in physique sporting events. For example, she described that a personal crisis became a powerful motivator for her to gain control over her life.

> *“he was like my first love if you want to say that, and he broke up with me and I was completely heartbroken, so it was bit like one of them, I’ll show you, so I contacted his best friend, who is a coach, and he prep me for my first show and I won and I got addicted to it, it was great”* (Julie).

Regardless of their initial reasons for starting their competitive journeys, three females may have shown symptoms of checking behaviour, a core feature of obsessive-compulsive disorder (Kachani et al., 2014; Vartanian & Grisham, 2012) which is often observed in individuals with ED (Davis & Scott-Robertson, 2000) and muscle dysmorphia (Mitchell et al., 2017). Jenna explained: “*Am I lean enough? You look in the mirror every day, every time you go to the toilet, you are lifting your top up to look how you are”*, and Katie shared “It got to the point actually, I think I’d become obsessed with the scale weight. So, I started getting on the scales every single day, and then I was just like ‘I haven’t lost anything’. However, it was not a surprise to Linda who articulated, “*It is a nature of the sport really. We are obsessed over our bodies”.* Whilst some research suggest that there is a moderate relationship between body checking and obsessive compulsory disorder (Vartanian & Grisham, 2011), previous literature also warns that females with a predisposition to body dysmorphia and ED could potentially result in exacerbating symptoms when partaking in the physique sports (Goldfield et al., 1998; Mitchell et al., 2017).

6.3.2 Theme 2: Body changes

This theme describes the lived experiences associated with changing the women's bodies to meet competition requirements in pre-competition. This was moving upwards to present the journey towards reaching their goal (*i.e.,* competition). However, as participants began the climb to the top of the rollercoaster, this was often not a pleasant ride. Rather, the sport is physically demanding, and the ride is arduous, slow and a struggle. Lisa described "*more cardio than you've probably ever done and you're eating a lot less than you've probably ever have*". In addition, most athletes described their dietary intake as structured, and gradually restricted over a prolonged period of time:

> *"My calories were around 800 calories a day, so that got dropped, but it didn't get dropped immediately, it was like each week"* (Katie)

> *"Very structured, I followed a set plan with my nutrition, so I'd get given, this is what you are eating, this is the amount, 5 to 6 times a day and that would slowly reduce the calories over time, leading up to the (competition) stage usually"* (Julie)

"It got to one point where I would be weighing peas and there couldn't be 51 grams of peas it had to be 50 because my god if I ate that extra pea. You know as well as trivial as it sounds." (Jenna)

Athletes emphasized structure and self-control as prerequisite for the demanding regime that is necessary when competing in physique sports, which confirms with previous literature of willpower and discipline associated with dieting in male counterparts (Bjoernestad et al., 2013), and is possibly linked to an underlying vulnerability to DE seen in some competitive general female athletes (Stirling & Kerr, 2012).

The body changes were not without health compromise and mental struggle. During their journey, most participants reported negative physiological stress such as fatigue and insomnia, which has also been shown in athletes showing symptoms of RED-S (Tayne et al., 2019) and previous studies in FP athletes (Aspridis et al., 2014; Probert et al., 2007). As Elise and Julie contend:

"Sometimes to be fair I felt more exhausted mentally rather than the physically, which I know that probably was the kind of like the first effect because my body was tired, but I was just so, so determined that I wanted to get to that leanness" (Elise)

> *"but it was known as prep insomnia it was a known thing and it was just something you dealt with, like there wasn't something...it was just something you put up with"* (Julie)

Here, athletes continued the climb towards an ideal body and competitive achievements despite experiencing negative psychological and physiological symptoms (*i*.e., mental dysfunctions such as potential secondary amenorrhea (the absence of menstrual cycles for three months or more after menarche (Redman & Loucks, 2005)), fatigue, irritability, and sleeping disorders). For example, Jenna reported *"I didn't have a period for 3 years, I experienced it (menstrual disruption) when I became very very lean"*. Although Elise may also have showed symptoms of secondary amenorrhea, she admitted the loss of menstruation was perceived beneficial for her performance.

> *"I think I lost my period from February and even when I stopped competing or my last competition at the first half of the year, it was in June and the next one was in October, I didn't get my period back despite my calories increased for like 2-3 months. So yea probably that was quite worried, but you know on the other hand it was quite handy, but yea I lost a few months of period "(*Elise)

In this stage of the journey, while not confirmed in this study, the menstrual disruption may indicate symptoms of prolonged RED-S, aligning with prior quantitative research (Mathisen et al., 2019; Halliday et al., 2016; Hulmi et al., 2017; Morsu et al., 2023) and parallels findings seen in chapter 4 (section 5.5, Study 3).

For some athletes, joy was also experienced during the pre-competition period. Jenna, Kerry, Linda and Beth reported that as they were moving closer to the competition day it was "*exciting*", "*fun*" and "*fascinating*" to see how their bodies were transforming towards the lean body 'ideal'. Those positive feelings were further emphasized during the period immediate pre-ceding competition. For example, Beth stated:

> *"It was exciting cause I was like ah it's nearly here but then I didn't want it to be over either, I was like aw no, like this is the last week, this is it, once this…that day is over, it's over."*

Amelia, Linda and Jenna also connected body changes to self-confidence and self-love. For example, Amelia mentioned *"I am always at my most confident when I am that lean"* and Katie described *"I was like 'ok I'm happy with this now, like, I like the look of my body and I feel a lot more confident',* while Linda explained *"But I love on prep how athletic I look and there are certain parts of my body I really start to admire, and I love my athletic physique".*

Julie speculated that during the pre-competition period, body composition goals may become more important than health for some FP athletes.

> *"I think the fact that you got that goal that means so much to you, you kind of brush it to one side, so your goal becomes more important than actual health"* (Julie).

From this perspective, the perceived benefits of competition may mask and outweigh the negative health consequences of extreme dieting, as also observed in female sports fields (Stirling & Kerr, 2012). Thus, as athletes make progress on the rollercoaster, the journey is both arduous and precarious, but sometimes joyous and their attention remains focused on reaching the top.

6.3.3 Theme 3) Public success with private isolation

As they approached and engaged in competition, the participants emphasised experiencing rewarding and positive feelings as they stepped on stage in front of an audience. At the summit of this rollercoaster, participants expressed feelings of euphoria, pride and sense of success. These feelings were present regardless of whether they won or lost the competition and linked to the presentation of their bodies that represent hard work and sacrifice. For example:

> *"I felt like a sense of achievement, I was so proud of myself. Yeah, it felt really good"* (Katie)

> *"I felt emotional because you had worked so hard for so long and then this is kind of like your end product almost and just like proud as well, like a sense of accomplishment*

> *and that you have done it, like no matter what, you are on stage and you have done it"* (Lisa)

During this stage, athletes appeared to develop an athletic identity, which was connected to self-esteem and pride. These findings are consistent with previous research observed among more muscular divisions of FP athletes (Aspridis et al., 2014; Grogan et al., 2004; Probert et al., 2007).

Although predominantly a positive moment, the peak of the rollercoaster, also included a paradoxical transition. Specifically, some athletes realised that competing in the sport does not provide sustained feelings of positivity, and this moment was typically transient.

> *"What brought me into competing was because I thought I was going to be happy when I looked like that. Then I realised when I look like that, I was happy, but it was only for like a very short amount of time"* (Kerry)

Like Kerry, other participants also pensively discussed that the challenges of competing in the sport can make them feel socially isolated. For example, Jenna expressed feelings of isolation because of the intense focus on nutrition and training:

> *"It definitely affects your relationship with parents, loved ones, friends because you isolate yourself and you become*

> *selfish, really selfish, like nothing else matters it's me, my diet, my training"* (Jenna).

All participants would limit attendance of social events due to the dedication to the sport, which subsequently had a negative impact on friendships and family life.

> *"I lost a few friends because I stopped going out drinking and they were like 'well we don't really want to know you anymore'. So that was like fine, and now I have got like a close group of friends and they still don't really understand it if I'm honest"* (Katie).

This may specifically lead to some of the athletes' perceived lack of understanding of the emotional and physical effects they are experiencing, and this was considered as a barrier to receiving social support.

> *"I didn't have anyone watching finals or nationals and, in a way, I was sad about it, but I didn't want to like force people to come and see me because they are not interested. I'm sure they would have done if I asked them, but I just kind of left it. I don't think people are that supportive, but that's more because they didn't understand it more so than that they weren't interested"* (Kerry)

The interplay between FP sports and stigma, as well as FP sports and self-isolation, is well-documented and can operate in a concurrent and bidirectional manner (Aspridis et al., 2014; Probert & Leberman, 2009; Shilling & Bunsell, 2009). Kerry's reluctance to seek support and her hesitation, driven by others' lack of understanding, exemplify how stigma may contribute to her isolation, and in turn, isolation reinforces the stigma. Thus, whilst at the top of the journey, these females may exude a public sense of confidence, paradoxically and privately, however, they may have concerns about isolation.

6.3.4 Theme 4: Physical and psychological tension

Once the competition had finished, all participants began a rapid descent from the ‘high’ of their lean ideal body. Most of the interviewed athletes were binge eating or consumed excessive amounts of “treats”, which had been restricted in the pre-competition period.

> *“I mean even on the day of the competition I came off stage and I had a huge bag of steak McCoy crisp, erm peanut butter, Reece’s peanut butter cups and I sat there, and I literally just shovelled it. I wasn’t hungry”* (Katie)

> *“I think a lot more people are starting to reverse diet. So, they are carrying on with a really really low-calorie diet and then they slowly upping the calories so that their bodyweight slowly regains, and you don’t have so many psychological issues which I think is really great. I have*

> *never been able to do that personally. I always binged and then I put on a bit of body fat"* (Amelia)

> *"So, the slightest amount of food that I would eat, oh God, my stomach would bloat. I'd feel lethargic, I'd end up with a lot of stomach cramps a lot of the time. I think that was obviously if they were a very carbohydrate-rich meal, so I just had to be really careful post-show"* (Katie)

The consequences of this rapid descent from their optimal competition body composition were stark. In agreement with work from Greenleaf (2002), athletes described how post-competition effects can result in tension and body dissatisfaction because of the weight regain. Some athletes felt guilt and low self-esteem as a result of deviating from their structured nutrition plan and the athletes are experiencing a sudden drop to the baseline.

> *"So, it was weird to sort of like get that layer of fat back. It felt like a shield had cut on top of your muscles and your abs had got softer, your legs got softer, your arms got softer. Then I was like 'ah! I don't like this!' So, I did develop some kind of body issues around that time because as I say when I went on holiday, I felt so uncomfortable"* (Kerry)

> *"It affected me like, I started gaining weight immensely, and it was like literally, it was noticeable. I mean the weight gain is obviously noticeable anyway because you're no longer on a strict diet. But even after that it got to the point where I was starting to look like overweight again, and I was like "wow". So basically, I had to go back into the gym doing stupid amounts of cardio again just to keep my weight down"* (Katie)

Post competition, females were not keen to display their bodies.

> *"So, they will have a new pose up to competitions and one about the show day, and then they disappear for like a month, 2 months, even longer. You're wondering whether they disappear because they just want to have time on their own, or because they feel sad in themselves and don't want to be seen when they are bigger"* (Kerry)

These results are consistent with the contention of Stephan & Bilard, (2003) that retiring athletes pass through a crisis provoked by an awareness of their deteriorating physical appearance. For the current participants however, this was not a retiring transition, but a competition season transition, which could be weeks or months, and may be experienced frequently over the course of a year. It has consistently been shown that body dissatisfaction can be a risk factor for eating pathology and exercise addictions (McArdle et al., 2016). At this stage of the journey, some participants reported losing control of their diet and eating habits.

> *"And it is almost an uncontrollable urge to eat that you have…. But I was so scared of putting the weight on that I thought the only way to actually manage it was to eat it so everyone didn't think I was being a weirdo, and then throw it up"* (Amelia)

> *"I think I developed really unhealthy eating patterns, and a lot of girls do, but they are embarrassed to talk about it, so they won't talk about it. Then that's when you start to isolate more, because you are embarrassed of your habits"* (Kerry)

Some participants also found it difficult to disclose any body image and eating behaviour issues. They identified these talks as taboo, and expressed feelings of shame, guilt and embarrassment. Their efforts to mask their body and weight concerns and inappropriate eating behaviours often led to further isolation in the post-competition period. This finding is consistent with previous work (Papathomas & Lavallee, 2010) in which researcher reported that disclosure may endanger these established personal and social understandings of self, thus posing a threat to identity. Consequently, the act of concealment leads to shame and social isolation.

“I went to my coach for the results, I didn’t go to him to help me with binge eating and they got that, and to be fair I don’t think I ever told him that I did binge eat, so, you can’t take that onboard anyway, I was quite secretive about it. So, no I didn't have any support, my mum didn’t know that about that, nobody really knew about it” (Julie)

“no one talks about that, like they talk about the glitz and glam of show day and prepping and like being restrictive and like feeling, everyone talks about feeling shit in preparation, but no one is talking about feeling shit after the show and what is going on afterwards, it’s almost taboo. Maybe people see it as like well you shouldn’t feel shit cause you’re eating again” (Lisa).

“But I was so scared of putting the weight on that I thought the only way to actually manage it was to eat it, so everyone didn’t think I was being a weirdo, and then throw it up” (Amelia)

“Even though it was properly like a normal portion and eating like 2 cookies after a meal is not a binge, but in my head, it was a big binge. So, I think I developed really unhealthy eating patterns, and a lot of girls do, but there are embarrassed to talk about it, so they won’t talk about

it. Then that's when you start to isolate more, because you are embarrassed of your habits (Kerry)"

As such, the observed taboo makes it a struggle for many participants, and in most participants, this is hidden away from the public. As Lisa implies, it may be less threatening for people to turn a blind eye and avoid the situation than to assist, similarly observed in other aesthetic sports (*e.g.,* gymnastics) (Papathomas & Lavallee, 2010). These findings suggest that taboos about DE and/or EDs may also be present within the subculture of physique sports. Whether novice FP athletes (who are starting their competitive journey) are exposed to these experiences, remains unclear. It was however reported that the full story of what it takes to achieve body ideal is not fully disclosed with the novice FP athletes.

> *"Girls seeing the glamour on stage and wanting to look like that but not necessarily getting the full story of what it takes. They want to look like that, but they don't necessarily understand, that you don't look like that 99% of the time. You're normally feeling like shit.'* (Julie)."

6.3.5 Theme 5: Aftercare

A novel aspect of the current study also sought the experiences and narratives on aftercare, and in doing so identified care is needed at different stages of the journey, and specifically, this should be of a multidisciplinary nature. FP athletes experience multiple transitioning periods by continually entering in-season and out of season phases throughout their career. This inevitably leads to a 'dynamic physical, psychological and social roller-coaster' experience. Indeed, sometime after the rapid descent from the high of competition, the women in this study made the decision to either leave the sport or start a journey on the next rollercoaster (Figure 6.1). Most of the participants had the intention of returning to dieting. For example, Elise reported: "*I haven't seen my body yet at its best, so I would like to get as lean as possible just to see that kind of muscle separation and stuff, that's probably what's keeping me going* ". While two participants wanted to quit their athletic career, for example Kerry reported: *"I think because of all the health complications that I have had personally I wouldn't want to go back to like a strict preparation diets. For me the mental impact that's been happening, more than the physical aspects".* Kerry explained the concept of losing her dominant identity immediately post-competition, and as such, felt the transition period to her former self was a challenging process. This finding shows that tension associated with the commitment and dedication to maintain the body ideal, persist into the post-competition period allowing no or little recovery of psychological, social and physical health from competition. It appears the struggle in this transition was reported by eight participants. For example, the following were quoted:

> *"You feel empty because you've been working so hard for something, and then suddenly you just have to try and be normal. So that was like a weird experience and that kept me in that diet circle, it kept me I wanted to compete again and again, because I needed something to focus on."* (Kerry)

"I'd gone from being completely lean for 3 years back-to-back. To now being big moo face, puffy ankles, swollen thick neck, and there was nothing I could do about it. It just was like…it broke me. I just couldn't comprehend in my brain why, it was happening." (Jenna)

"So, it's one of them, so you'll guilt trip yourself and then you'll try and go back to competition preparation, and you just don't know which way to go because that's the thing you've known for so many months" (Nina)

"After the first competition, I would go immediately back into a preparation to get it under control because I knew if I had that goal again it would be a structure, which is why my body didn't progress because I was going through like a binge-purge cycle every time, so my body didn't have any stabilities with the calories" (Julie)

"Suddenly you've got like time off after competition, that's like a mental breakdown, you're trying to relax but you're just thinking, oh my gosh I'm not in the gym. I'm just either gaining some body fat or lose some muscle "(Elise).

From a welfare perspective, this raises questions regarding the care that these women receive. Many participants described that coaches exerted a powerful influence and were held with particular reverence and respect:

> *"At the end of the day I mean the competition messed with my menstrual cycle and there's completely nothing that I could do. It was literally taking the word of and the advice of my coach who had been doing it for years, she was experienced. So, you have to trust in them."* (Katie)

Interestingly, the majority of the participants (i.e., seven participants) believed that more education and regulations for coaches is warranted. For instance, athletes explained:

> *"Whether there is some sort of like board, whereas if you are a coach for competitors you have to be part of a certain… like a member to a certain board or something and you're under their regulations to provide a certain duty of care"* (Beth)

> *"I do think there should be something post-show for people, particularly first-timers who have got no idea what is going to come post show. Because as I said I think it's very taboo what happens post-show for people, and I think federations probably don't highlight that either* (Lisa)"

> *"I think there is a lot they could do. They could take a lot more healthier practices and like go on nutrition courses to figure out how you can lose weight healthier and not just take food away from people which I think there is a lot of coaches do."* (Amelia)

It emerged that from the athletes' perspectives, coaches are unaware of the specialist multidisciplinary practitioners available for athletes to be signposted to, or how to help athletes access them. For Amelia that particularly meant post-competition, which is a crucial time of receiving special support *"I had no guidance post competition of what I could actually do*." As such, athletes felt they did not receive sufficient support from their coaches. Therefore, future work should explore coaches' practices in physique sports.

More awareness and development of more comprehensive education programmes and qualified multidisciplinary support networks within physique sports organisations could be a particularly effective way to care for athletes on their journey. The required multidisciplinary support including coaches, medical doctors, psychologists and nutritionists. For example, care offered during the pre-competition phase could involve social support that integrates family and friends into the journey. Social support, defined as any social interaction that involves the exchange of resources and is meant to help the receiver achieve a desired goal (Poucher et al., 2018) becomes an important aspect in female athletes lives to manage stress, feel loved, reassurance, cared for, boost self-esteem and selfcompetence as well as prevent loneliness. Given that the sport is a biopsychosocial process and the drive for muscularity in the sport has been shown to impact social relationships (Edwards et al., 2021), FP athletes may struggle succeeding.

However, during the post-competition phase, care should involve psychological support in the management of feelings of guilt, shame and identity loss. For example, seeking help from a registered psychologist to address particularities. For more details readers are directed to the review by Bratland-Sanda & Sundgot-Borgen, (2013). Overall, these findings indicate the need to educate athletes, but also coaches working with the individual athlete, so they understand when they need to offer further interdisciplinary support. Without such support, athletes can be left ignored, ashamed, undiagnosed and therefore untreated.

Regarding building on the experiences of FP athletes, future research should consider that the ideal athletic identity at the peak of the rollercoaster is not a sustainable phase, and FP athletes entering the sport without knowledge of this, can cause identity confusion. A model to guide future research in this respect is that of 'Athletic Identity' (Brewer et al., 1993). The theoretical framework suggests that pre-competition was a controlled and gradual process that engendered positive outcomes (Baghurst et al., 2014; Whitehead et al., 2020). However, some of the participants also expressed negative connotations regarding the self-isolation required for this phase, creating an intriguing paradox. Many of the physique athletes recounted a sense of identity loss in the post-competition phase, which frequently occurred in tandem with DE patterns. Consequently, the FP athletes experienced weight regain, and feelings of shame, guilt and embarrassment often causing a decline into dieting or quitting their sporting career entirely. This may be an interesting line of research that is coherent with previous work identifying physique sports as a particularly aesthetic-pressured environment, and FP athletes as a population at risk of ED (Goldfield et al., 1998; Whitehead et al., 2020). Therefore, such tension for 'self' puts a great burden on athletes, and the lack of specialist care is likely to further amplify the health implications experienced.

6.4 Limitations and strengths

Despite the contributions of the study, it is necessary to highlight limitations that readers must consider in their interpretation of the findings. Firstly, the present study did not explore detailed themes and information relating to FP athletes' specific dietary and training practices, and how these are aligned with the evidence-based literature. Nevertheless, recent work has begun to explore these parameters (Mitchell et al., 2017) on male physique athletes. Secondly, whilst reliability is needed in quantitative research, it can be considered ineffective for qualitative studies due to the concerns around unitization and disagreements of meanings (Smith & McGannon, 2018). Sparkes (2013) states 'we cannot step into the same stream twice' (Sparkes 2013, p.180) (similarly quoted by Heraclitus in Plato's Cratylus, Section 402a) (McShane and Böckenholt 2014). However, to achieve rigour and quality, the study used a 'critical friend', who listened, challenged and provided critical feedback to the principal investigator's interpretation. Lastly, all interviews took place with only physique athletes from two regions (Northwest and East England, UK) with three athletes having had the same performance coach in the past. Thus, this data may provide a narrow perspective on this sample.

To provide credible accounts of the FP athletes' circumstances, the sample size was determined based on data saturation; that is when no new information was gathered (see data collection in the methods). In quantitative research, this sample size (n=10) may be viewed as a limitation. However, qualitative research, guided by different assumptions and goals from quantitative research, values small sample studies as strengths and does not aim for statistical generalisability (Smith and Sparkes, 2020). In quantitative research, researchers judge generalisation from reliable results of representative samples via probability sampling. While in qualitative methods, the goal is to provide an in-depth understanding of these participants' experiences with emotions where findings generalise through transferability (*ie.*, when readers feel the research overlaps with their own situation, and they intuitively transfer the findings to their own context) (Smith 2017). As such, it is the reader who reflects upon the FP athletes' experiences and judges if the insights are transferable to their context (if appropriate) (Smith 2017). We remind readers this study does not provide practitioners with guidelines regarding the treatment of physique athletes but raises awareness and help inform decisions regarding practice.

To this end, this study utilised a research methodology which promotes voices of ten FP athletes. This research demonstrates that rich data on these experiences can be obtained from listening to FP athletes' biological, psychological and social dimensions within the sport. Findings suggest that future researchers should value women's voices and accordingly implement a co-designed methodology for any action-style research. Involving FP athletes in the methodological design of studies (*e.g.*, provide a forum to express behaviours and experiences) may further improve the effectiveness and feasibility of interventions. Future work should look at interventions *with* individuals rather than *on* individuals to optimise the FP athletes' needs and welfare. Particularly, future research should; *i)* examine the narratives of key stakeholders (*e.g.*, coaches, judges, chief executive officers of organisations and partners) and *ii)* develop and pilot test an easily accessible multidisciplinary support network and mandatory courses available for any FP athletes and coaches, and this is to be reinforced within the organisations. Currently, there is no structure in place in terms of educating athletes and/or coaches on areas of weight management and psychophysiological health. The inclusion of evidence-based education, and a sports science/welfare manager who will oversee a qualified nutritionist, licensed psychologist and medical practitioners in physique organisations may embed a more holistic approach to athlete support and actively promote the use of specialist care at different stages of the athletes' career.

6.5 Conclusion

In conclusion, this interpretive study provides a comprehensive and accurate account into female's embodied experiences in physique sports. Athletes' personal perspectives can provide practitioners with knowledge and awareness of how physique sports affect females physical, psychological and social health.

By listening to the voices of ten FP athletes, findings showed that these FP athletes undergo a rollercoaster of mixed emotions and experiences during different competitive phases. In particular, the post-competition period may present a "battle" between their former self and the athletic identity leading to feelings of embarrassment, guilt, and taboo. Herein, future interventions should build upon these foundations by being multidisciplinary and longitudinal in nature to consider the temporal nature of being a physique athlete. Given the precariousness of the overall journey, prompted by extreme nutritional and physical practices, care is necessary to ensure physique athletes are physically, psychologically and socially healthy. This warrants further consideration, and the discussion that follows will explore if and how a multidisciplinary network of practitioners could support athletes at different stages of their rollercoaster experience.

[redacted] 7. General Discussion

7.1 Summary of aims, findings and practical applications

The studies in this thesis take a holistic view of both dietary and training practices, for the harmonisation of health and optimal aesthetic appearance. Specifically, in Chapters 1 and 2, a series of both laboratory and web-based studies investigating the eating and training practices employed by FP athletes are documented. Moreover, the effects on psychological, physiological and social implications across different phases of the competitive season using multi-methods approaches are detailed in Chapters 5 and 6. An overview of each specific aim, findings and practical applications are outlined below (Table 7.1).

Table 7.1: *A summary of the study aims, main findings and practical implications for this thesis*

Study (Chapter number)	Aims	Main findings	Practical Implications
Study 1 (Chapter 3)	1) To investigate the weight loss history, practices and influential sources of dieting during pre-competition in a large cohort of FP athletes. 2) A secondary aim was to determine the extent of DE symptoms among FP athletes,	Independent of division or experience level, 158 FP athletes practice both acute (body water manipulation via water loading) and chronic weight loss (gradual dieting, food restrictions, and excessive exercise) methods to acquire their physique aspirations. Notably, Figure novice athletes reported greater patterns of weight cycling, compared to the other groups *(e.g.,* Figure experienced, Fitness Novice). Lastly, 37% of FP athletes were at risk of developing ED, with 42% using two PWCM throughout their competitive season.	These findings may indicate a need to embed targeted sport-specific education packages covering a range of sport nutrition topics including acute weight loss practices, restrictive nutrition, RED-S and ED (for example how to recognise these signs) in the bodybuilding and fitness organisation's curriculum for the safe and effective use of pre-competition weight management practices. Given FP athletes reliance on coaches for information on dieting practices, education should be targeted at coaches. This also highlights the need to promote and encourage the role of qualified nutritionists and sport dietitians to support athletes on weight management. This is particularly important for novice athletes, and those competing in higher divisions where aesthetic appearance (*i.e.*, lower FM) might result in them be more susceptible to DE symptoms.

Study 2 (Chapter 4)	To quantify pre-competition energy intakes, training practices and wellbeing from FP athletes using an observational study design	Using a web-based platform, and one-to-one consultations, nine free-living FP athletes reported to reduce their BM and absolute EI with no changes in relative values of macronutrients during a pre-competition block. Moreover, aerobic training duration was increased whereas resistance training duration and internal resistance TL decreased. As a result, out of the psychometric measurements, vigour was only reduced in pre-competition.	Coaches and athletes may use these data to help prepare and plan appropriate dietary and training periodisation and load management in the pre-competition phase, whilst acknowledging the effects this may have on vigour. On-going monitoring of psychological health (mood states and well-being) using practical questionnaire tools during the pre-competition phase will allow the practitioners and FP athletes to assess and manage psychological health, training performance, overtraining and injury prevention. Nevertheless, these dietary and training approaches may be considered as an effective approach to weight loss by any resistance trained athlete.
Study 3 (Chapter 5)	To assess the physiological and psychological responses of an international female physique athlete pre-, during- and post-competition: A case report	These findings demonstrate that during recovery from competition, an experienced FP athlete competing at the international level (and in the division which requires least leanness) experienced rebound hyperphagia response and sign of hyperinsulinemia with compromised psychological health. Furthermore, pre-competition permitted negative effects associated with RED-S (some which may not normalise after 12 weeks of feeding).	There appears to be a need for multidisciplinary support interventions which are embedded in physique for improved athlete practices. Unlike many team and individual sports, physique athletes often only have access to coaches and judges. For example, to have access and awareness to a psychologist with specialism in DE, and a nutritionist may be highly valued by the FP athletes during the recovery phase. Importantly, evidence informed nutrition practices should be a cornerstone feature, as improper nutritional practices which are not safe may lead to long-term LEA and associated psychological and physical health implications.

Study 4 (Chapter 6)	To explore the lived experiences of females' physique athletes sporting careers using a qualitative method.	Using semi-structured interviews (a qualitative method) with ten FP athletes, subjective and rich data on their lived experienced during their sporting career were obtained. It was shown that these specific athletes undergo a 'rollercoaster journey' of distinct emotions, experiences, and health implications across different phases of the competitive season. This overall theme represented five key subthemes: 1) Starting the journey, 2) body changes, 3) public success with private isolation, 4) physical and psychological tension and 5) aftercare.	Athlete care from multidisciplinary practitioners may be valuable at different phases of the annual schedule to make sure that physique sport athletes are physically, psychologically, and socially healthy throughout their sporting careers. Establishing a system that facilitates easy access to qualified multidisciplinary support practitioners and promoted by physique organisations is essential. This will allow athletes to speak with and work closely together with practitioners at any time point during any phase and be better supported. To implement such system requires a long-term work with key stakeholders and where organisational financial benefits is not compromised. For example, profit from participation cannot be compromised because this often goes towards costs for venues when hosting events, winner earnings. It is necessary to develop, implement, and pilot test such system in the physique organisations allowing an easy access to required multidisciplinary support for improved athlete welfare and care.

7.2 General findings

7.2.1 Weight loss and eating behaviours in FP athletes

In Chapter 3, when stratifying the participant sample by disciplines and experience levels, the Figure novice athletes lost, and regained, the most weight (*i.e.*, weight cycling the most) throughout the competitive cycle. Consequently, these athletes displayed a greater number of DE symptoms including high frequency of binge eating. This might be owing to the stricter body composition requirements in this division (*i.e.*, the requirement to be leaner than Bikini Fitness and Women's Fitness), along with them possibly be exhibiting DE eating symptoms prior to entering the sport in hopes that the sport will appease the symptoms. This has been observed recently in male counterparts (Mitchell et al., 2017), whereby a higher prevalence of DE symptoms were observed in novices compared to experienced athletes, but their behavioural symptoms may hinder longer term engagement in the sport, thus they discontinue competing again. Moreover, Mitchell et al., (2017) suggested that these symptoms alleviate in longer term engagement in the sport. The present study was the first to detail the prevalence of dieting procedures used by FP athletes. Irrespective of division or experience level, athletes used acute weight loss (*e.g.,* water and salt manipulation) and chronic (*e.g.,* gradual dieting and increasing exercise) practices to acquire optimal body compositions. Thus, there was a definite need to assess the specific details and changes in their nutritional and training practices in the pre-competition phase (Chapter 4) in a group of competitive FP athletes.

7.2.2 Nutritional and training practices in FP athletes

In Chapter 4, dietary intake, macronutrient distribution and training practices were assessed using self-reporting methods in free-living FP athletes. FP athletes utilised a prolonged period of time prior to competition to reduce BM by gradually increasing weekly aerobic training durations, whilst concomitantly reducing the duration and internal loads of weekly resistance training sessions. Furthermore, regarding nutrition, mean absolute EI reduced across time, from a reduction in protein and fat intake, whilst CHO intakes remained low and unchanged during the pre-competition phase. Nevertheless, EI and all macronutrients in relative values did not change across time-points (-12WK, -4WK and -1WK) measured. Consequently, of all psychometric measurements, only vigour changed from -12 weeks to -1 week prior to competition. Taken together, this may suggest that well-being and overall mood disturbance are not affected by these athletes' pre-competition nutrition and training practices. To gain a holistic and robust evaluation of their physiological and psychological health across the competitive cycle, it was important to assess whether athletes are at risk of LEA and other associated RED-S symptoms during pre- and post-competition using laboratory methods (Chapter 5).

7.2.3 Physiological and psychological health implications in a competitive cycle of an FP athlete (a case report)

In Chapter 5, the case report showed how an experienced FP athlete competing at the international level achieved her aesthetic aspirations which resulted in alterations to physiological and psychological health markers pre- and post-competition. In the recovery phase (Phase 3), the athlete substantially increased EI (when compared to -2D) along with increases in BM (+19%), Σ_{8SKf} (+28 mm). Additionally, there was elevated levels of fasting insulin and cardiometabolic markers (fasting insulin and TG/HDL-C ratio), indicating a hyperphagia response. In the pre-competition phase, the athlete experienced various abnormal health markers related to physiology (*i.e.*, endocrine systems) and psychology (*e.g.*, mood states); some of which (including testosterone and FT3) did not fully recover after 12 weeks of refeeding to the clinical references. Weight cycling can worsen negative body image, and contribute to a cycle of unhealthy weight management techniques to counterbalance weight regain (Stukenborg et al., 2021). As such, it remained crucial to assess FP athletes' personal lived experiences not only through one competitive cycle but also throughout their whole sporting career (Chapter 6).

7.2.4 Personal lived experiences of FP athletes' sporting careers

In Chapter 6, FP athletes' perceptions and lived experiences in the sport were examined. This Chapter shows that these interviewed FP athletes experienced a 'dynamic physical, psychological and social rollercoaster'. Within this, five key subthemes were identified: Starting the journey, body changes, public success with private isolation, physical and psychological tension and aftercare which manifest themselves uniquely at different stages of a competitive cycle. Using the 'voices' of the FP athletes, tailored regulations and coach education should be implemented to improve the care of athletes participating in the sport.

More awareness and development of more comprehensive education programmes and qualified multidisciplinary support networks (*i.e.*, the Sport and Exercise Nutrition Register) within physique sports organisations could be a particularly effective way to care for athletes on their journey, however this needs to be designed, implemented and pilot tested. Findings offer credible insights into the complex interplay between the body composition ideal, culture and dieting practices, and how this results in biological, psychological, and social health implications in a sample of FP athletes across their sporting career.

7.3 Study strengths and potential limitations

Limitations for each study can be found within each study chapter. The key strengths for the project are that the study 1 (Chapter 3) recruited the largest sample size (n= 158) of FP athletes in the Northern hemisphere (*i.e.*, Scandinavia and UK) to date. Study 1 also included extensive new knowledge and showed a greater detail (than previously reported) of dieting procedures used to acquire optimal body compositions within different divisions and experiences levels of FP athletes.

The PPI method used in Chapter 4 provided a rationale for the web-based platform design in this study. Co-creation in the design of the research in sport science for health is unique and not often considered (Cockcroft, 2020), despite it ensuring that the research is relevant, appropriate, and positive for participant recruitment and retention. Chapter 4 included multiple-methods of dietary assessment to gain an improved representation of habitual intakes in FP athletes in a pre-competition block. Given that Chapter 4 was a study on free-living individuals which is particularly important when analysing habitual dietary intakes and training practices as opposed to controlled conditions in a laboratory, the web-based study design allowed participants to report data at a time and place (*e.g.*, gym and home) that was convenient for them.

Key strengths of Chapter 5 included the objective measures (anthropometrics, comprehensive profile of clinical blood biomarkers and hydration status) which had not been previously employed, despite their practical relevance. Examining longitudinally post-competition recovery (> 10 weeks post-competition) also strengthened the understanding of the long-term physiological and psychological health implications experienced by athletes. Lastly, a key strength of Chapter 6 was using the athletes' voices to try and understand them, and their personal lived experiences. This allowed for a holistic understanding of what it means to be a FP athlete.

It is plausible that the results from those sampled in Chapter 2, 3 and 4 may not be the entirely representative of FP athletes in England or further afield. However, the practices observed resemble those described in previous studies and suggest a level of homogeneity. Nevertheless, Chapter 6 does not seek to generalise to a wider population, rather it seeks to provide in-depth insights into the specific experiences of participants recruited.

Participants were asked to complete an online questionnaire and diary for nutrition and training (without complete supervision) in Chapter 3 and 4, respectively. The self-reporting method is a potential limitation given the tendency towards under-reporting of DE practices (Torstveit et al., 2008) and dietary intake (Capling et al., 2017a) among athlete populations. Responses may also be influenced by the athletes' beliefs or subjective perceptions, introducing potential bias. However, to help minimise these errors it was decided to use anonymity for the survey in Chapter 3 and using multiple methods for dietary assessments in Chapter 4. Although coaches may have had an input on athletes' dietary and training practices in Chapter

4, the aim focussed on what free-living FP athletes were consuming and training, rather than who orchestrated athletes' practices. As such, this should be a separate research study which investigates in-depth, what the coaches are doing and what guidance they provide the FP athletes.

A major limitation in Chapter 5, was the lack of a true baseline and as such her dataset does not include the total change from baseline to competition day or baseline to recovery, due to the participant has not commenced her pre-competition phase before the -4WK measurement time point. Indeed, we direct readers to section 2.13 prior to conducting research on FP athletes. Furthermore, no measure of FFM or EA estimates (owing to the lack of assessments of daily energy expenditure or EEE) was in Chapter 4 and Chapter 5. As such, this limits the interpretation of reduced EA and RED-S symptoms. The collection of exercise energy expenditure may have further explained the mechanisms of some of these health outcomes.

7.4 Recommendations for further research

Building upon the findings from this thesis and consideration of the strengths and limitations discussed above, this section offers further research directions. Moving forward, future research should:

1. Validate the EAT-26 questionnaire presented in Study 1 (Chapter 4), in cohorts of physique athletes to confirm its sensitivity and specificity.
2. Directly measure daily energy expenditure/exercise energy expenditure over the course of a pre-competition phase to allow a robust calculation of energy balance and EA. For the most accurate TEI results, the use of doubly labelled water should be performed.

3. Further analysis of leptin, and ghrelin metabolic and bone turnover markers will allow a more global view of the neuroendocrine and bone metabolic interactions of both LEA and rebound hyperphagia during pre-competition and long-term post-competition periods.
4. A study which explores the perceptions of dieting practices and health consequences amongst key stakeholders (coaches, judges, and organisation owners) in physique sports is warranted. This could be achieved using focus groups or individual interviews.
5. A future study should validate and implement a nutrition-specific educational platform for different stakeholder groups and a multidisciplinary access network system for the improvement of weight management behaviours, health and welfare. This could examine the efficacy of such a change on the perceptions of athletes and wider stakeholder groups.

7.5 Conclusions

In conclusion, the general aim of this thesis was to investigate eating behaviours and training practices among FP athletes from the UK during the pre-competition phase (Chapter 3, 4) and the subsequent impact on psychological and physiological health (Chapter 5). Furthermore, this thesis aimed to obtain an in-depth understanding of personal lived experiences and provide a platform on where to focus strategies and interventional studies for change (Chapter 6).

The thesis was undertaken to contribute to the research of female physique sports. The use of weight-loss practices was similar across divisions and experience levels. Notably, Figure novice athletes showed a tendency towards weight cycling and great risk for ED. FP athletes reported coaches and other physique athletes to be the greatest influences on dieting and weight loss efforts. Despite large differences between FP athletes, dietary and training variables are systematically manipulated over a 12-week pre-competition phase (Chapter 4) with changes in BM, (within) daily TEI and training variables. As a result, no change was observed in self-reported daily well-being or total mood disturbance. Collectively, Chapters 3 and 4, may provide further insights into the specific practices used to acquire optimal body compositions, the influential person during this process and further direction for the development and delivery of nutrition education programmes to increase awareness and improve knowledge of EA, within-day energy balance and nutrient timing, in cases where the athlete needs to lose BM. The health implications, including perturbations to psychophysiological systems associated with RED-S and rebound hyperphagia responses across different phases of the competition season (pre-competition, competition week and recovery phase), were evident in one experienced FP athlete (Chapter 5). This highlighted the importance of providing highly individualised support and care to FP athletes. Furthermore, listening to the FP athletes' voices contributed to a deeper level of understanding of their personal lived experience within the sport from the perspective of information rich-cases (Chapter 6). Within this, five key subthemes were identified: Starting the journey, body changes, public success with private isolation, physical and psychological tension and aftercare which manifest themselves uniquely at different stages of a 'rollercoaster experience'. The thesis may be used to improve pre- and post-competition planning and monitoring methods and assist in the co-design and action-style interventions outlined in future research. Finally, there is a clear need for a multidisciplinary care platform in the sport and educational packages to be embedded in organisations. If such systems and curricula were enforced into the sporting governing bodies to start with, this may allow FP athletes to gain more positive experiences and improve the long-term health and welfare.

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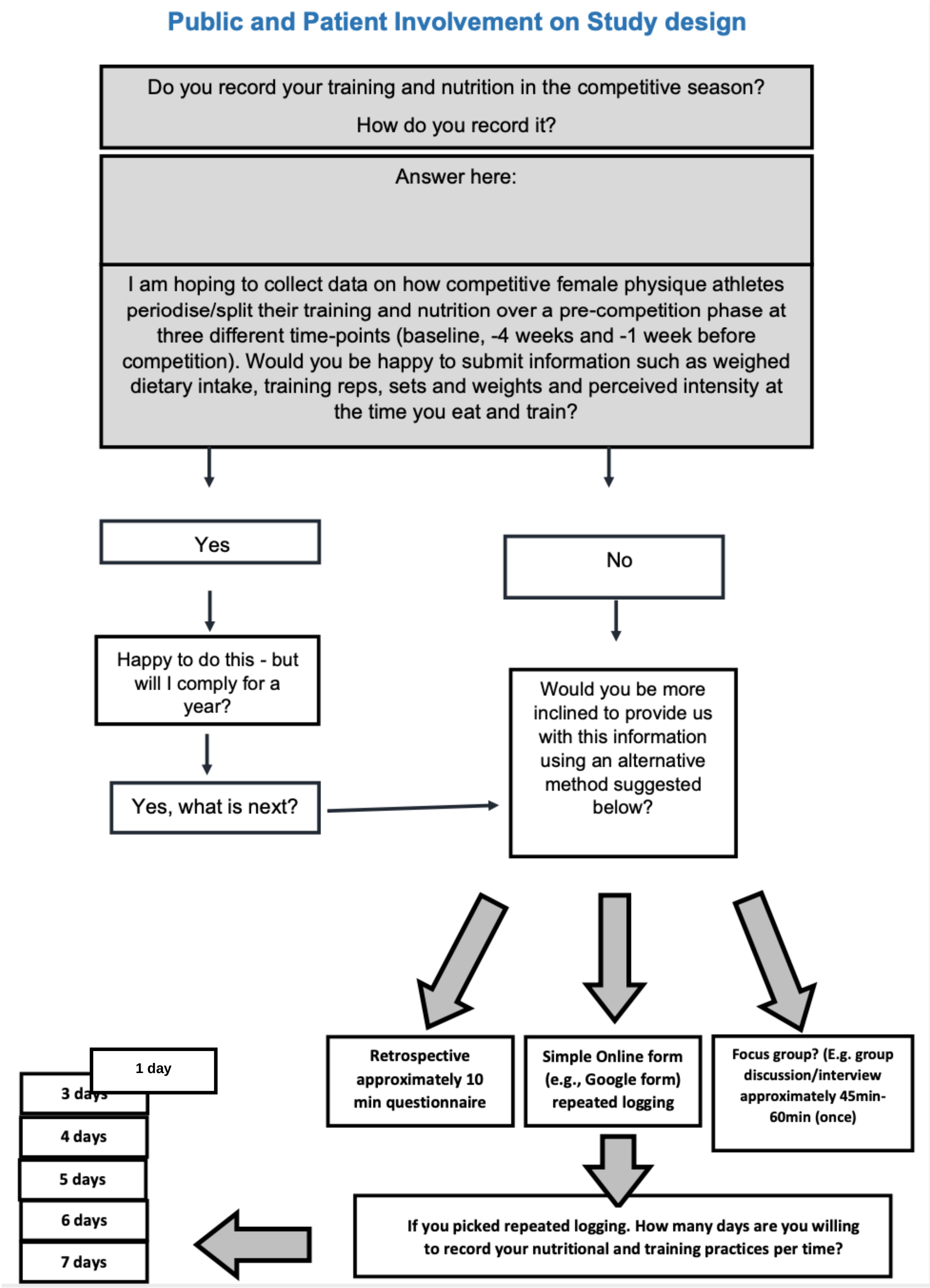
[redacted] 9. Appendix

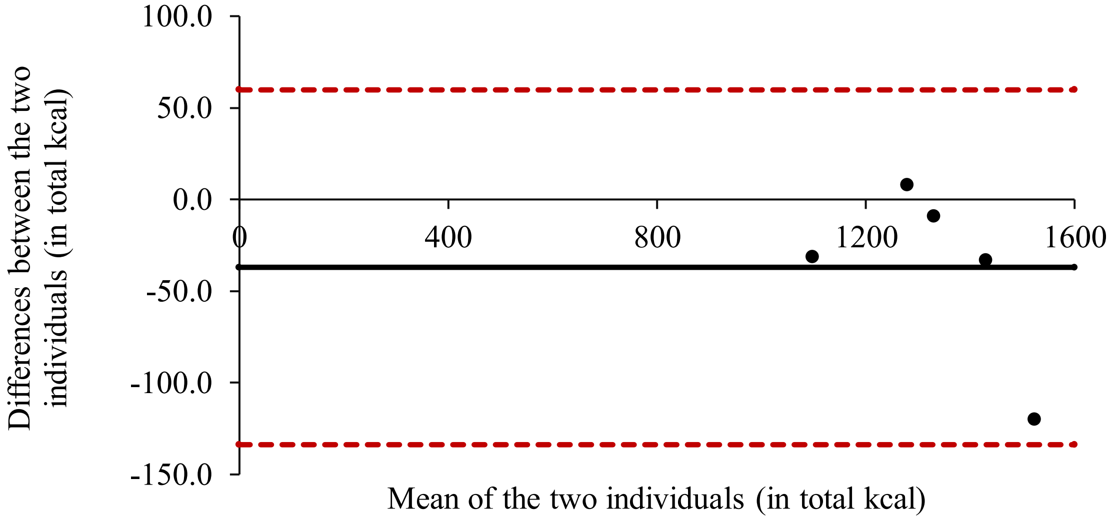
9.1 Comments from constructive validity process on survey (in chapter 3)

"For the cigarette question you should properly ask about nicotine and vape products, as I know some competitors use these for either perceived thermogenic or appetite-suppressing effects"
"I think you it would be useful if you defined what gradual dieting means in this questionnaire, so competitors can answer this right"
"There are 2 Diet Pill questions. The first about "carb/fat blockers" and they may assume that they should list Fat "Burners" here. So perhaps ask the "Fat Burners" questions just before the "Fat Blockers" question and they are more like to answer both correctly."
"Perhaps mention a little earlier in the preamble to the survey that all results are anonymised so you don't turn them off early (although I know this may have been prepared by your ethics committee and so you may not be able to alter"

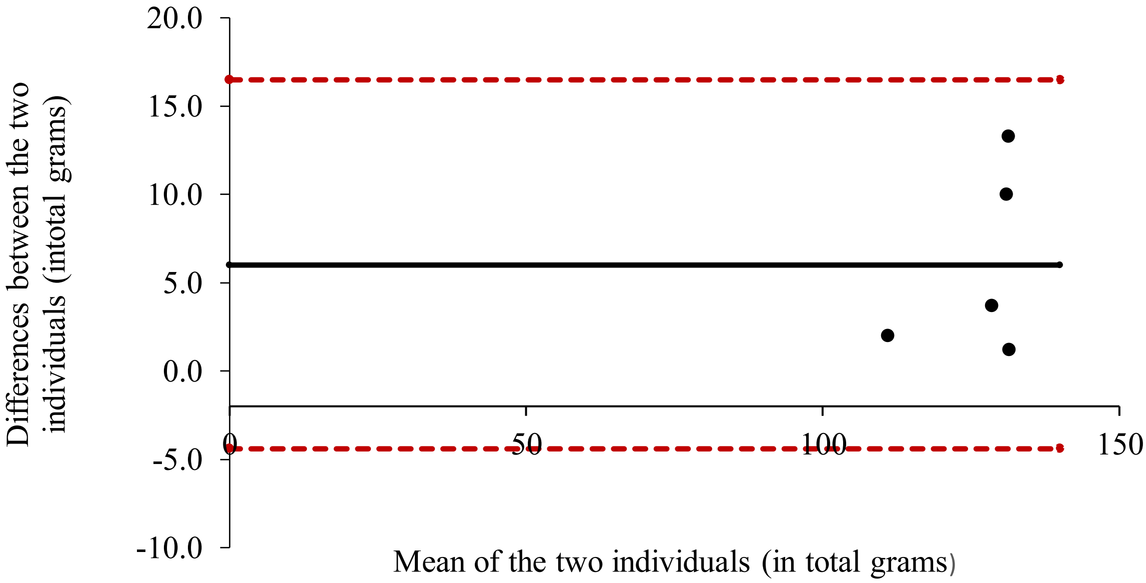
9.2 Patient and Public Involvement Trial Questionnaire (used chapter 4)



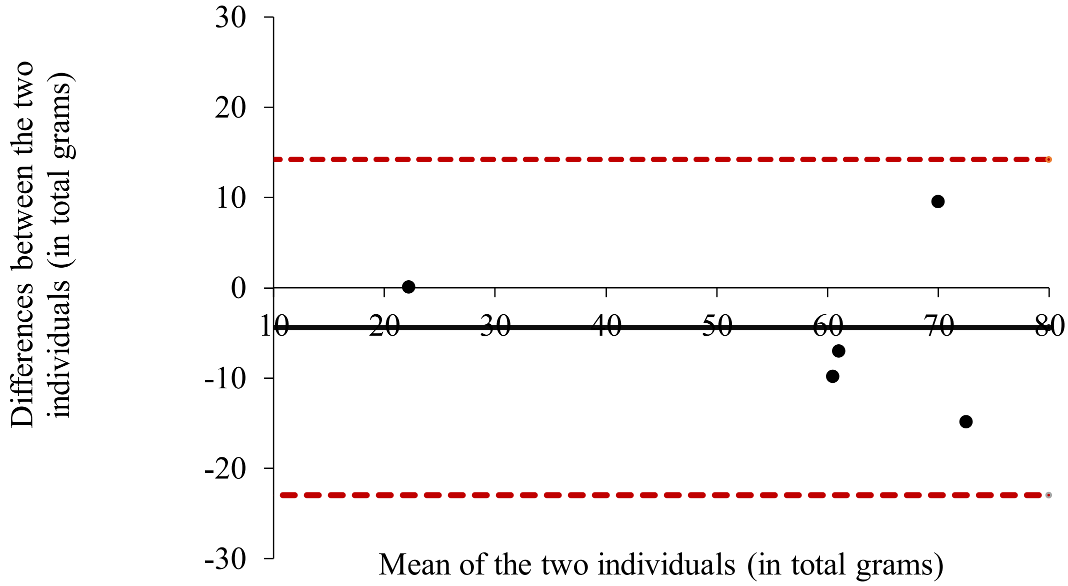
9.3 Bland-Altman plots (from chapter 4)



A



B



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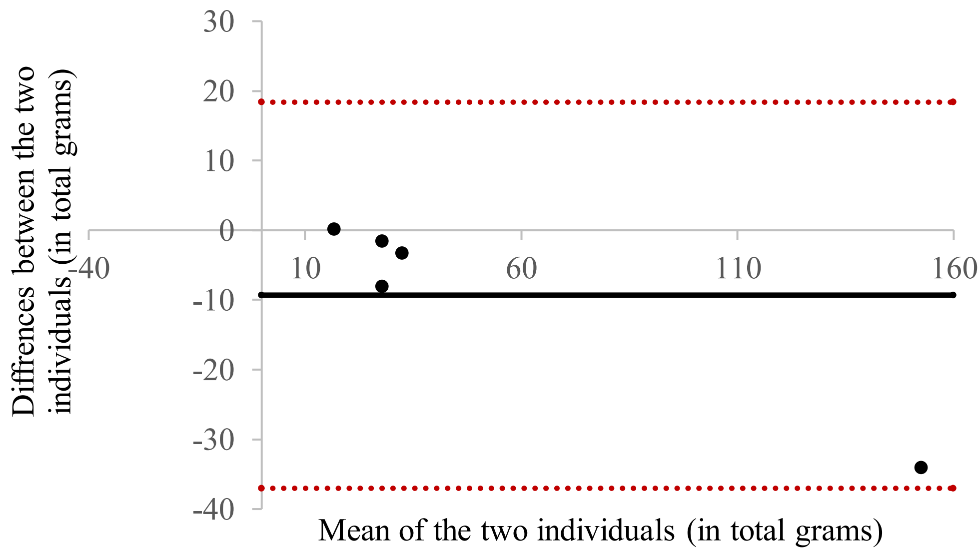

D

Figure 9.2.1- *Bland-Altman plots for the EI (A), carbohydrates (B), proteins (C) and fats (D) analysis between two individuals. The central line represents the absolute average difference between individuals, while the upper and lower lines in dark red represents upper and lower limits of agreements, respectively (± 1.96 standard deviations (SD)).*

9.4 Brunel Mood Scale (used in Chapter 4 and 5)

BRUNEL MOOD SCALE QUESTIONNAIRE

BRUMS is a standard validated psychological test. The questionnaire contains 24 words that describe feelings people have. The test requires the participant to indicate for each word(s) or statement how you have been feeling in the past week including today.

Instructions: Below is a list of words that describe feelings. Please read each one carefully. Then tick the box which describes *how you have felt in the past week including today*. Make sure you answer every question. There is no time limit.

Participant Number_________________________

Day and Date ______________________________

Time Point_________________________________

Mood state	Not at all	A little	Moderately	Quite a lot	Extremely
Tension					
Panicky					
Anxious					
Nervous					
Worried					
Anger					
Annoyed					
Bitter					
Angry					

Bad tempered					
Depression					
Depressed					
Downhearted					
Unhappy					
Miserable					
Fatigue					
Worn out					
Exhausted					
Sleepy					
Tired					
Vigour					
Lively					
Energetic					
Active					
Alert					
Confusion					
Confused					
Muddled					
Mixed-up					
Uncertain					

9.5 Pittsburgh Sleep Quality Index (PSQI) questionnaire used in Chapter 5

Participant number ____ Date_________

Sleep Quality Assessment (PSQI)

What is PSQI, and what is it measuring?

The Pittsburgh Sleep Quality Index (PSQI) is an effective instrument used to measure the quality and patterns of sleep in adults. It differentiates "poor" from "good" sleep quality by measuring seven areas (components): subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction over the last month.

INSTRUCTIONS:

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

During the past month,

1. When have you usually gone to bed? ______________________________
2. How long (in minutes) has it taken you to fall asleep each night? ______________________________
3. What time have you usually gotten up in the morning? ______________________________
4. A. How many hours of actual sleep did you get at night? ______________________________
   B. How many hours were you in bed? ______________________________

5. During the past month, how often have you had trouble sleeping because you	Not during the past month (0)	Less than once a week (1)	Once or twice a week (2)	Three or more times a week (3)
A. Cannot get to sleep within 30 minutes				
B. Wake up in the middle of the night or early morning				
C. Have to get up to use the bathroom				
D. Cannot breathe comfortably				
E. Cough or snore loudly				
F. Feel too cold				
G. Feel too hot				
H. Have bad dreams				
I. Have pain				
J. Other reason (s), please describe, including how often you have had trouble sleeping because of this reason (s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
9. During the past month, how would you rate your sleep quality overall?	Very good (0)	Fairly good (1)	Fairly bad (2)	Very bad (3)

Scoring

Component 1	#9 Score	C1 __________
Component 2	#2 Score (<15min (0), 16-30min (1), 31-60 min (2), >60min (3)) + #5a Score (if sum is equal 0=0; 1-2=1; 3-4=2; 5-6=3)	C2 __________
Component 3	#4 Score (>7(0), 6-7 (1), 5-6 (2), <5 (3)	C3 __________
Component 4	(total # of hours asleep) / (total # of hours in bed) x 100 >85%=0, 75%-84%=!, 65%-74%=2, <65%=3	C4 __________
Component 5	# sum of scores 5b to 5j (0=0; 1-9=1; 10-18=2; 19-27=3)	C5 __________
Component 6	#6 Score	C6 __________
Component 7	#7 Score + #8 score (0=0; 1-2=1; 3-4=2; 5-6=3)	C7 __________

Add the seven component scores together __________________ ***Global PSQI*** _______________

A total score of "5" or greater is indicative of poor sleep quality.
If you scored "5" or more it is suggested that you discuss your sleep habits with a healthcare provider

9.6 Low energy availability in females questionnaire and scoring (used in chapter 5)

October 30, 2013 [THE LEAF-Q]

The low energy availability in females questionnaire (LEAF –Q), focuses on physiological symptoms of insufficient energy intake. The following pages contain questions regarding injuries, gastrointestinal and reproductive function. We appreciate you taking the time to fill out the LEAF-Q and the reply will be treated as confidential.

Name: ______________________

Address: ______________________

____

E-mail: ______________________

Cell: ____________

Profession: ______________________

Education: ______________________

Age: ________(years)

Height: ________(cm) Weight: ________(kg)

Your highest weight with your present height: ________ (kg)
(excluding pregnancy)

Your lowest weight with your present height: ________ (kg)

Do you smoke? Yes ☐ No ☐

Do you use any medication (excluding oral contraceptives)? Yes ☐ No ☐

If yes, what kind of medication?______________________

Your normal amount of training (average) – number of hours per week and what kind of exercise, such as running, swimming, bicycling, strength training, technique training etc.:

____

____

____

Comments or further information regarding exercise:______________________

____

____

1. Injuries **Mark the response that most accurately describes your situation**

A: Have you had absences from your training, or participation in competitions during the last year due to injuries?

☐ No, not at all ☐ Yes, once or twice ☐ Yes, three or four times ☐ Yes, five times or more

A1: If yes, for how many days absence from training or participation in competition due to injuries have you had in the last year?

☐ 1-7 days ☐ 8-14 days ☐ 15-21 days ☐ 22 days or more

A2: If yes, what kind of injuries have you had in the last year? ______

______

Comments or further information regarding injuries: ______

______

______

2. Gastro intestinal function

A: Do you feel gaseous or bloated in the abdomen, also when you do not have your period?

☐ Yes, several times a day ☐ Yes, several times a week

☐ Yes, once or twice a week or more seldom ☐ Rarely or never

B: Do you get cramps or stomach ache which cannot be related to your menstruation?

☐ Yes, several times a day ☐ Yes, several times a week

☐ Yes, once or twice a week or more seldom ☐ Rarely or never

C: How often do you have bowel movements on average?

☐ Several times a day ☐ Once a day ☐ Every second day

☐ Twice a week ☐ Once a week or more rarely

D: How would you describe your normal stool?

☐ Normal (soft) ☐ Diarrhoea-like (watery) ☐ Hard and dry

Comments regarding gastrointestinal function: ______

______

3. Menstrual function and use of contraceptives

3.1 Contraceptives

Mark the response that most accurately describes your situation

A: Do you use oral contraceptives?

☐ Yes ☐ No

A1: If yes, why do you use oral contraceptives?

☐ Contraception ☐ Reduction of menstruation pains ☐ Reduction of bleeding

☐ To regulate the menstrual cycle in relation to performances etc..

☐ Otherwise menstruation stops

☐ Other____

A2: If no, have you used oral contraceptives earlier?

☐ Yes ☐ No

A2:1 If yes, when and for how long?____________________________

B: Do you use any other kind of hormonal contraceptives? (e.g. hormonal implant or coil)

☐ Yes ☐ No

B1: If yes, what kind?

☐ Hormonal patches ☐ Hormonal ring ☐ Hormonal coil ☐ Hormonal implant ☐ Other

3.2 Menstrual function

Mark the response that most accurately describes your situation

A: How old were when you had your first period?

☐ 11 years or younger ☐ 12-14 years ☐ 15 years or older ☐ I don't remember

☐ I have never menstruated (If you have answered "I have never menstruated" there are no further questions to answer)

B: Did your first menstruation come naturally (by itself)?

☐ Yes ☐ No ☐ I don't remember

B1: If no, what kind of treatment was used to start your menstrual cycle?

☐ Hormonal treatment ☐ Weight gain

☐ Reduced amount of exercise ☐ Other

C: Do you have normal menstruation?

☐ Yes ☐ No **(go to question C6)** ☐ I don't know **(go to question C6)**

C1: If yes, when was your last period?

☐ 0-4 weeks ago ☐ 1-2 months ago ☐ 3-4 months ago ☐ 5 months ago or more

C2: If yes, are your periods regular? (Every 28th to 34th day)

☐ Yes, most of the time ☐ No, mostly not

C3: If yes, for how many days do you normally bleed?

☐ 1-2 days ☐ 3-4 days ☐ 5-6 days ☐ 7-8 days ☐ 9 days or more

C4: If yes, have you ever had problems with heavy menstrual bleeding?

☐ Yes ☐ No

C5: If yes, how many periods have you had during the last year?

☐ 12 or more ☐ 9-11 ☐ 6-8 ☐ 3-5 ☐ 0-2

3.2 Menstrual function

Mark the response that most accurately describes your situation

C6: If no or "I don't remember", when did you have your last period?

- ☐ 2-3 months ago
- ☐ 4-5 months ago
- ☐ 6 months ago or more
- ☐ I'm pregnant and therefore do not menstruate

D: Have your periods ever stopped for 3 consecutive months or longer (besides pregnancy)?

- ☐ No, never
- ☐ Yes, it has happened before
- ☐ Yes, that's the situation now

E: Do you experience that your menstruation changes when you increase your exercise intensity, frequency or duration?

- ☐ Yes
- ☐ No

E1: If yes, how? (Check one or more options)

- ☐ I bleed less
- ☐ I bleed fewer days
- ☐ My menstruations stops
- ☐ I bleed more
- ☐ I bleed more days

1. A: **0** No, not at all, **1** Yes, once or twice, **2** Yes, three or four times, **3** Yes, five times or more

1. A1: **1** 1-7 days, **2** 8-14 days, **3** 15-21 days, **4** 22 days or more

2. A: **3** Yes, several times a day, **2** Yes, several times a week, **1** Yes, once or twice a week or more seldom,

0 Rarely or never

2. B: **3** Yes, several times a day, **2** Yes, several times a week, **1** Yes, once or twice a week or more seldom,

0 Rarely or never

2. C: **1** Several times a day, **0** Once a day, **2** Every second day, **3** Twice a week, **4** Once a week or more rarely

2. D: **0** Normal, **1** Diarrhoea-like, **2** Hard and dry

3.1 A1: **0** Contraception, **0** Reduction of menstruation pains, **0** Reduction of bleeding,

0 To regulate the menstrual cycle in relation to performances etc.., **1** Otherwise menstruation stops

3.2 A: **0** 11 years or younger, **0** 12-14 years, **1** 15 years or older, **0** I don't remember,

8 I have never menstruated

3.2 B: **0**Yes, **1** No, **1** I don't remember

3.2 B1: **1** Hormonal treatment, **1** Weight gain, **1** Reduced amount of exercise, **1** Other

3.2 C: **0** Yes, **2** No (go to question 3.2 C6), **1** I don't know (go to question 3.2 C6)

3.2 C1: **0** 0-4 weeks ago, **1** 1-2 months ago, **2** 3-4 months ago, **3** 5 months ago or more

3.2 C2: **0** Yes, most of the time, **1** No, mostly not

3.2 C3: **1** 1-2 days, **0** 3-4 days, **0** 5-6 days, **0** 7-8 days, **0** 9 days or more

3.2 C4: **0** Yes, **0** No

3.2 C5: **0** 12 or more, **1** 9-11, **2** 6-8, **3** 3-5, **4** 0-2

3.2 C6: **1** 2-3 months ago, **2** 4-5 months ago, **3** 6 months ago or more

0 I'm pregnant and therefore do not menstruate

3.2 D: **0** No, never, **1** Yes, it has happened before, **2** Yes, that's the situation now

3.2 E: **1** Yes, **0** No

3.2 E1: **1** I bleed less, **1** I bleed fewer days, **2** My menstruations stops, **0** I bleed more, **0** I bleed more days

9.7 Menstrual history questionnaire (used in chapter 5)

MENSTRUAL CYCLE DETAILS

(All information is fully confidential)

Please circle the answer where appropriate.

Participant number:

Age:

Date of birth:

1) Have you had regular periods in the last six months? YES NO

2) How long in days is your menstrual cycle, from day 1 of bleeding (period) to day 1 of the next period?

_________DAYS

3) Is the above time the same between periods? YES NO

If the answer was NO, please state the irregularity:

____

____

____

____

4) How many days does your menstrual (blood) flow last?

__________DAYS

5) Do you get pain during your period? YES

NO

If YES, please state the symptoms and the days during the cycle when you suffer:

____

____

____

____

6) Do you avoid exercise during your period? YES

NO

If YES, please state your reasons for avoiding exercise:

____

____

____

____

7) Do you take any medication or hormones to regulate your menstrual cycle?

YES

NO

If YES, please state what you take and how often?

____

____

____

8) Do you take any other medication?

YES

NO

If YES, please state what you take and how often?

____

____

____

9) Have you previously used any form of hormonal contraception (oral contraceptive, implant, injection, coil)?

YES

NO

If YES, please state the type of contraception used and the date that you ceased using it?

____

____

____

10) When did you have your last period (day 1)?

____

NB: Please contact your personal GP or National Health Services (NHS) helpline or email support if they experience any difficulty after completion of this questionnaire. NHS Contact Centre: Email support: England.contactus@nhs.net. Helpline:03003112233.

9.8 Coefficient variation, range and sensitivity* of measurements (from chapter 5)

Biomarker	CV%	CV Range	Sen*	Biomarker	CV%	CV Range	Sen*
Adjusted Calcium (mmol/L)	< 2.5	0.2 – 5.0	0.2	**Ferritin (ug.L^{-1})**			0.5
ALB (g/L)	< 9.5	7.7 – 62.5.0	3.0	**FSH (mlU/mL)**	< 4.5	6.0 –178	0.1
ALT (u/L)	< 3.3	21.5 – 546.0	5.0	**GLOB (U/L)**	< 2.1	17.5 – 41.2	2.0
ALP (U/L)	< 2.1	52.6 – 1025.0	5.0	**HDL (mmol/L)**	< 1.8	0.2 – 3.5	0.1
B12 (pg/mL)	< 5.2	176 – 1890.0	100.0	**K (mmol/L)**	< 1.6	1.5 – 9.6	0.2
Bicarbonate (mml.L^{-1})			2.0	**LDL (mmol/L)**	< 2.1	1.5 – 6.1	0.1
BIL (mmol/L)	< 3.3	8.7 – 544.0	2.5	**LH (mlU/mL)**	< 2.2	5.8 – 164.0	0.1
CHOL (mmol/L)	< 1.6	2.0 – 7.4	0.1	**Mg (mmol/L)**	< 1.3	0.6 – 1.4	0.1
Cortisol (nmol/L)	< 2.8	124.0 – 691.0	0.1	**Na (mmol/L)**	< 1.1	88.7 – 175.8	10.0
Cl (mmol/L)	< 1.0	67.1 – 138.0	3.9	**Oestradiol (pg/mL)**	< 10.6	27.4 – 2720	5.0
CK (U/L)	< 1.4	73.3 – 1990.0	7.0	**PHOS (mg/dL)**	< 1.4	0.7 – 6.2	0.1
FT3 (pmol/L)	< 7.2	1.3 – 46.0	0.6	**PRL (mlU/mL)**	< 1.8	182 – 4477.0	1.0
FT4 (pmol/L)	< 8.4	1.6 – 92.7	0.5	**PROG (nmol/L)**	<3.3	0.5-174	0.2

CRP (nmol/L)	<3.7	3.9- 3333.0	2.9	**SHBG (nmol/L)**	< 4.0	13.7 – 219	0.3
CRE (mmol/L)	< 1.2	68.3 – 2286.0	5.0	**Testosterone (nmol/L)**	< 4.4	1.98 – 20.98	0.02
Oestradiol (pg/mL)	< 10.6	27.4 – 2720.0	5.0	**Triglycerides (mmol/L)**	< 1.9	1.2 – 9.2	0.1
Folate (ng/mL)	< 16.1	1.7 – 16.4	1.2	**TSH (mlU/mL)**	< 7.2	0.1 – 9.4	0.1
Insulin (mU/mL)	< 4.9	5.9 – 425.0	0.2	**Total Protein (g/L)**	< 2.5	20.4 – 87.8	2.0
Iron mmol/L)	< 1.8	11.3 – 55.1	0.9	**UREA (nmol/L)**	< 1.2	7.2 – 35.1	0.5
IGF-1(nmol/L)	< 5.4	2.9 – 86.9	0.25	**25(OH)D (nmol/L)**	< 10	2.5 – 625.0	5.0
Ferritin (mg/L)	< 23.4	1.1 – 1449.0	0.5				

9.9 Semi-structured interview guide

TWO INTERVIEWS; 1) Introduction + icebreaker; 2) Deep insights)
Using a semi-structured approach, the main questions (or similar) will be asked, with the points beneath each one potential area to navigate during the interview.

I would like to thank you for giving your valuable time to take part in this interview. For the audio, my name is Nura and I am a PhD research student at Liverpool John Mores University in sport nutrition and physiology. In this interview, I would like to explore what being a physique athlete means to you and how have your personal experiences affected you. As such there is no 'right' or 'wrong' answers and you should feel free to answer my questions in your own way and at your own pace. As part of this study, you will eb expected to take part in two-parts interview with a break in between. The reason I am running these interviews with female physique athletes is to try and understand your feelings and perceptions on the strategies used and any potential health implications involved in your sporting career. This will allow me to inform further guidelines for improvement of health and welfare in the female physique community.

First interview

1. Can you tell me how old are you and how long have you been involved with resistance training?
2. Can you tell me how long have you been involved with physique competitions?
    i. What got you into this activity? and What and who influenced you to start?
    ii. Can you remember a key moment when you decided you wanted to become a physique athlete? Describe this moment to me.
    iii. How would you describe the major differences in your body now as a physique athlete and the body you had before participation?
    iv. Do you feel any different living in these different body types? If so, please give me some examples.
3. If you could describe the perfect physique body -what would it be?
4. Is there a point where you don't want to be that muscular or lean? Can you give me an example of a famous person or division or person you are inspired by?
5. Can you tell me what it requires to be successful in physique competitions?

I. What was it like to step on stage and show your body and what emotions were you aware of at that time?
II. How did that feel?
III. Does it feel different when you are not placing?
IV. How does it feel after the competition?

6. What makes your training and nutrition different compared to other weight restricted sports such as dancers, combat sport athletes and weightlifters?
7. How do you perceive physique competitions?
   I. How did your last competition affect you in the long term?
   II. Do you see yourself as an athlete? Why?

<u>BREAK</u>

Second interview:

8. The weeks leading up to competition, take me through the whole process
   i. Describe to me your dietary and training habits leading up to competition?
   ii. How different are these habits compared to post-competition and off-season?
   iii. Do you monitor your progress? If so, how do you feel when you monitor your physique?
   iv. How do feel during competition week "peak week"? Why do you think that might be?
   v. What else do you remember about the peak week?
   vi. Do you feel there are any specific health concerns associated with the period when physique athletes are preparing for a competition?
   vii. How do you feel with these health concerns?
   viii. Can you explain whether this is common among physique athletes?

9. How do you think your peers (*e.g.,* family, partner and friends) perceive your participation in the sport?

10. Can you explain to me if and how your social activities with family, partner and friends changes throughout your participation in the sport?
11. Following competition, take me through the first weeks of post-competition
    ix. How did you feel immediately after your competition?
    x. How did you feel 1-4 weeks post-competition?
    xi. Have you experienced any health issues during that time-period? Why you think that might be?
    xii. How did you deal with these issues?
    xiii. How do you feel now?
12. Do you feel there are any health concerns associated with being a physique athlete in general?
13. What influences the practices that you use to achieve the desired physique?
    xiv. Coach?
    xv. Time?
    xvi. Internet?
    xvii. Other athletes?
14. How did you feel when you last time got on stage?
15. What are your feelings/thoughts about your future in the sport?
16. How do you feel about your health and performance moving forward?
17. In your opinion, is there anything the organisations can do to support athletes' health?
18. In your opinion, is there anything the coaches can do to support athletes' health?
19. Would you say you have good nutritional knowledge?
    i. To lose weight?
    ii. For health?
20. What advice would you give to somebody thinking about competing in physique competitions?
21. Have we discussed everything? Is there any question or have something you want to tell or explain further?

Thank you! Your participation is appreciated

Themes	Sub-Theme	Coded data	Number of people
1. Starting the journey	**Social media mimesis**	*".You will look at them and see what they are doing, what they look like, 'what they are doing different to me, do I need to do something different?' So, you start comparing yourself quite a lot to other people." (Jenna)* *"I was really inspired by all the girls physiques, and the transformation pictures in particular. So that's when I got in touch" (Linda)* *"So, it's when your focused so much on other people, you start looking at yourself thinking well 'I'm not good enough'" (Katie)* *"So, I was looking on Facebook and looking at UK bodybuilding federations and came across WBBF in the UK and then I was scrolling through their Facebook feed and my first coach had put an advertisement" (Amelia)* *"it was around the time where, competitors on Instagram was becoming a bit of a thing, you know and people started to share more things. And it was around that time. And the more I saw of it, I was thinking oh I might…I quite like this" (Beth)* *"..to be fair it was when I started looking at the pictures of the girls on stage, I really liked the physique, how beautiful they were and kind of nice but muscly they were, maybe not muscly but the balanced body look like" (Elise)*	**6**
	Peers' influences	*"so it was like 'well I like the look of this' So then I started just resistance training with them and then once they got close to shows I was like 'I want to do one! "(Nina).* *So, I just, like with doing like the weights it just kind of grew and grew and people kept saying to me are you going to compete? (Lisa)*	**2**
	Vulnerability	*"he was like my first love if you want to say that, and he broke up with me and I was completely heartbroken, so it was bit like one of them, I'll show you, so I contacted his best friend, who is a coach, and he prep me for my first show and I won and I got addicted to it, it was great" (Julie).*	**1**

2. Body changes		*"I was like 'ok I'm happy with this now, like, I like the look of my body and I feel a lot more confident'." (Katie)* *I feel proud to be up there and I feel confident (Jenna)* *Then some people will enjoy the leanness and then feel less confident, as they become like, well as they gain body fat again, as they come towards off season. So yea mental health I think is like a concerning area (Beth)* *"I felt quite scared at first to be fair, but then when you are actually on stage it is amazing, like you've got all your family watching you and it is just awesome. They are dead proud of you, no matter what, where you placed, they are dead proud like (Nina)"* *"I felt emotional because you'd worked that hard for so long and then this is kind of like your end product almost and just like proud as well, like a sense of accomplishment and that you've done it" (Linda)* *"I feel more feminine than getting to that body stage leanness I felt ok because the muscles start to kind of showing up and so I just feeling fine and everyone was just, you know give me the complements, so obviously that was nice." (Elise)*	**5**
3. Physical and Psychological tension		*I do know, well I have come across a few individual females that have gained an eating disorder because of competing, or have had coming into competing. So that makes me think that that's a way of masking, a way of controlling." (Jenna)* *I don't think it was that prep I think it was the prep afterwards that I started making myself sick because I just couldn't cope with the like the post cope rebound anymore. I just wanted to stay that lean. (Amelia).* *"well a week after your competition, you are back in the mirror going 'I look huge, I've put on all of this weight.' And it wasn't the case I mean, I only gained a few pounds and I thought that I looked absolutely massive" (Katie)* *"Obviously physical health, people obviously have implications of like no period, like they are fatigues, but mental health, I really do feel like, that is something which is a concern." (Beth)*	

		"Tiredness. Just being really really tired. My sleep was really disruptive" (Linda) *"So, the slightest amount of food that I would eat, oh god my stomach would bloat. I'd feel lethargic, I'd end up with a lot of stomach cramps a lot of the time. I think that was obviously if they were a very carbohydrate-rich meal, so I just had to be really really careful post-show"* (Katie) *"I mean I was wearing a corset for quite a long time, like for prolonged hours a day so like 8 to 10 hours a day. Sometimes I was sleeping in it and at the time I thought I had to do it because I was told to do it"* (Kerry) *Firstly, I'd say, make sure you've got a healthy relationship with food and like your diet before you even compete, because if you don't have a healthy relationship with food, then you'll struggle with the diet, like 100%. Body image, like your confidence, how you feel about yourself* (Beth) *"And you binge, like you stick to your diet plan that your coach has given you, but because you've got no support there it's like you eat things in between it and then you will guilt trip yourself. You then end up with an eating disorder because you're eating and then you're like 'I've got to go and do a shit tonne of cardio because I've just eaten food.'"* (Nina) *"I went to him for the results, I didn't go to him to help me with binge eating and they got that and to be fair I don't think I ever told him that I did binge eat, so, you can't take that onboard anyway, I was quite secretive about it. So, no I didn't have any support, my mum didn't know that about that, nobody really knew about it"* (Julie) *" It can be a challenge sometimes emotionally as well when "ohh I want to wear this lovely dress, oh no sorry it is off-season I can't fit into that" and I think sometimes psychologically, that can be a difficult thing to deal with."* (Linda) *"I developed really unhealthy eating patterns, and a lot of girls do, but their do embarrassed to talk about it, so they won't talk about it. Then that's when you start to isolate you more, because you're embarrassed of your habits. "*(Kerry)	

		"Sometimes to be fair I felt more exhausted mentally rather than the physically, which I know that probably was the kind of like the first effect because my body was tired but I was just so, so determined that I wanted to get to that leanness or whatever "(Elise)	
4. After care		*"I would say a lot of people go about it the wrong way and look for coaches who have this absolutely amazing shape. I'd say that's not always the best factor, so I would always go from recommendations from people is the biggest." (Katie)* *"Yeh I think I wish that I had a coach that I could talk to about these things, because I think it kind of escalated in to like having low self-esteem" (Kerry)* *"So everyone goes through stages where they feel 'I'm not good enough. It's not gonna happen. I'm not going to be lean enough. I'm not going to loose the weight. I look rubbish.' And the coach that can ground you and bring you back day and say 'sort it out' y'know I'd say support and having that kind of relationship with a coach" (Jenna)* *"I think there is a lot they could do. They could take a lot more healthier practices and like go on nutrition courses to figure out how you can lose weight healthier and not just take food away from people which I think leave a lot of coaches do." (Amelia)* *"So if anything, there probably needs to be a bit more education for coaches on like how to sort of help people cope in that post-competition." (Beth)* *"Whether there is some sort of like board, whereas if you are a coach for competitors you have to be part of a certain… like a member to a certain board or something and you're under their regulations to provide a certain duty of care" (Beth)* *"You know and be a support network and not just my coach, you know you have got to be my support, you gotta be my backbone?' (Nina)* *"I went to a seminar a few weeks ago, Joe Highton he was, he said 'I'm not scared to put people on 700 calories, for a woman. I was like 'you're taking the piss.' like anorexic people*	

		don't eat that. You know what I mean? You are going into an eating disorder, you're stepping on very dangerous water when you put your woman on 700 calories" (Nina) *"Because I think especially from a coach, if a coach has been a bodybuilder, I think personally they just use methods that have worked on them." (Julie)* *"They should have to pass qualification to be a coach. You don't have to have a coach, you don't have qualify to be an online coach. Anyone could walk up the street and prep someone for competition"(Julie)* *I do think there should be something post show for people, particularly first timers who have got no idea what is going to come post show. Because as I said I think it's very taboo what happens post show for people and I think federations probably don't highlight that either (Lisa)* *"But the trouble is that anyone can just enter and compete a competition. You don't have to like prove anything, you don't necessarily have to have a coach to do it, you could just do it yourself" (Kerry)* *"Oh she but to be fair like I just said, I wouldn't really, I wouldn't really, she, I don't believe she' got the education in nutrition or sports science. I wouldn't really sit down with her and just take her advice from the very like with a very knowledgeable person" (Elise)*	