THE PSYCHOLOGICAL AND PHYSIOLOGICAL EFFECTS OF MAKING WEIGHT IN INTERNATIONAL LEVEL TAEKWONDO ATHLETES

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Abstract

International standard Taekwondo athletes are unique, given they are required to compete in two differing weight categories for both World (WT) and Olympic (OG) events, which have some of the largest differences amongst other making weight combat sports. Typically, this demographic will lose body mass (BM) via acute and chronic methods, in order to make the lower limit of a category. Despite a raft of literature examining the frequency, magnitude, occurrence and influences of these practices, the motivations to engage in this convention are still largely unknown. Additionally, few studies have investigated this population for both body composition and activity energy expenditures (AEE), utilising either criterion or field based measurement tools during periods of BM loss and as such, these athletes may be susceptible to low energy availability (LEA) leading to relative energy deficiency in sport (RED-S). Therefore, the main aim of this thesis was to examine the psychological and physiological health and performance consequences of making weight in international standard Taekwondo athletes.

Study 1 examined the frequency, magnitude, occurrence and influences of BM loss and making weight practices, in a cohort of 106 male and female Cadet, Junior and Senior Taekwondo athletes, directly after a weigh in at a major national championships. In agreement with previous research, there were no differences between sexes, however, for the first time this study highlighted key disparities in the frequency, magnitude and occurrence of BM loss and making weight practices between age groups. Additionally for the first time, the magnitudes between WT and OG weight category requirements were elucidated, showing relative BM losses which are far higher than previously characterised in this demographic. This study also highlighted the key stakeholder groups influencing the engagement in these practices, which in younger age groups was shown to be predominantly parents. Finally, it was conveyed that the nutritional and ergogenic dietary supplement knowledge of this group was largely poor when compared to optimal guidelines.

In Study 2, semi structured interviews were conducted with the key stakeholder groups (5 athletes, 5 coaches, 5 parents), as identified in Study 1. Again, high magnitudes of BM loss were described by all stakeholders in agreement with Study 1. Furthermore, each stakeholder group described their perceptions of the making weight process, with all expressing it can negatively affect health and performance, but was necessary to enhance advantages in competition. The nutritional and ergogenic dietary supplement knowledge of all stakeholder groups was poor as described in Study 1. All stakeholders agreed that education, targeted particularly at the coaches, alongside improvements in national and global federation making weight policies, were required to improve current practice.

Study 3 investigated the requirements of BM losses between the OG and WT categories in 18 international standard Taekwondo athletes, within 4 days prior to a competition weigh in. This emphasised the need to engage in extreme making weight practices in order to meet elected OG category allowances, as described in Studies 1 and 2. Additionally, the body composition of these athletes was examined utilising both dual x-ray absorptiometry (DXA) and various sum of skinfold ($\sum_{\text{SKf}}$) fat mass percentage

(FM%) equations. For the first time, this study highlighted body compositional differences between athletes of varying weight categories, where all of the cohort had low FM% (<11%). This study also demonstrated that only two of ten identified $\sum_{\mathrm{SKf}}$ FM% equations compared favourably in parallel to the criterion measurement of DXA, for the examination of body composition within this demographic in the field.

In Study 4, a laboratory simulated protocol was designed to mimic the activity profile and perceptual/physiological responses of international Taekwondo competition at various intensities. Utilising these protocols, AEE was assessed in a group of 8 male international standard Taekwondo athletes, employing both indirect calorimetry and portable actigraphy for comparison of assessment methods. AEE differed between conditions with both methods, highlighting the relevance of the various protocols for measures of workload intensity. Additionally, the portable actigraphy unit showed good agreement with indirect calorimetry, justifying its use for the measurement of AEE when utilised with this population in the field.

In Study 5, a periodised nutritional and training intervention was employed with an international standard Taekwondo athlete, requiring a >13% loss of BM for competition. Utilising the findings and methods of Studies 3 and 4, energy availability (EA) was examined and measures were taken throughout to examine the potential for RED-S consequences on both health and performance parameters. The athlete successfully achieved their elected weight category limit, with minimal negative associations of RED-S syndromes exhibited on markers of metabolic, endocrine, cardiovascular, bone turnover and psychological functions. Additionally there were no negative effects apparent on either tested maximal dynamic strength/power and cardiorespiratory conditioning or competitive performances. However, post competition there was a significant rebound hyperphagic response, congruent with BM overshoot and despite the success of the intervention, this should be given further consideration in the future.

This thesis serves as a means to improve the making weight practices of international standard Taekwondo athletes, by affording the ability to examine both body composition and AEE in the field, whilst providing a safe and effective intervention to lose BM without the negative associations of RED-S. However, despite this, the findings of this thesis also serve as a call to action to the national and global governing federations, in enhancing the education of key stakeholders in this sport, whilst considering the addition of more weight categories to reduce the incidence of extreme and dangerous making weight practices throughout older age divisions.

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Dedication

'I would like to dedicate this thesis to my father Denis, my inspiration, who has always pushed me to do my very best despite any obstacle. Il always remember that one day you brought home that poster and told me to live by it, I always have and I always will…NEVER EVER GIVE UP!'

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Declaration

I declare that the work in this thesis, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own. Additionally, all attempts have been made to ensure that the work is original, does not, to the best of my knowledge, breach any copyright laws and has not been taken from the work of others, apart from the works that have been fully acknowledged within the text.

Publications and presentations of the work within this thesis are listed as follows:

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List of Abbreviations

1RM = 1 Repetition Maximum

90% CI = 90% Confidence Intervals

95% CI = 95% Confidence Intervals

95% PI = 95% Prediction Intervals

β-Ctx = Beta-Carboxy-Terminal Cross-Lined Telopeptide

AEE = Activity Energy Expenditure

ALB = Albumin

ANOVA = Analysis of Variance

AT = Adaptive Thermogenesis

A/RWL = Acute/ Rapid Weight Loss

BDJ = Bounce Drop Jump

BIA = Bioelectrical Impedance Analysis

BLac = Blood Lactate

BM = Body Mass

BMC/D = Bone Mineral Content/Density

BR = Bilirubin

C = Cortisol

Ca^+ = Calcium

CHO = Carbohydrate

CHRM = Commercial Heart Rate Monitor

cm = Centimetres

CMJ = Counter Movement Jump

CO = Cardiac Output

CO_2 = Carbon Dioxide

Cr = Creatinine

CSD = Consensus Sleep Diary

CV = Coefficient of Variation

DIT = Diet Induced Thermogenesis

DLW – Doubly Labelled Water

DWBS = Daily Wellbeing Score

DXA = Dual X-ray Absorptiometry

EA = Energy Availability

EB = Energy Balance

ECG = Electrocardiogram

ECW = Extra Cellular Water

EE = Energy Expenditure

EEE = Exercise Energy Expenditure

EF = Left Ventricular Ejection Fraction

EI = Energy Intake

EIT = Ethanol Induced Thermogenesis

EPOC = Excess Post Oxygen Consumption

EUR = Eccentric Utilisation Ratio

F/V = Force/Velocity

FAT = Fat

FFM = Free Fat Mass

FM (%) = Fat Mass (Percentage)

FSH = Follicle Stimulating Hormone

GCT = Ground Contact Time

GH = Growth Hormone

GLOB = Globulin

HDL = High Density Lipoprotein

HR = Heart Rate

I = Insulin

ICW = Intra Cellular Water

IGF-1 = Insulin-Like Growth Factor

IOC = International Olympic Committee

JH = Jump Height

kcal = Kilocalorie

kg = Kilogram

L = Litres

LDL = Low Density Lipoprotein

LEA = Low Energy Availability·

LH = Luteinizing Hormone

LM = Lean Mass

LVEDV = Left Ventricular End-Diastolic Volume

m = Metres

$m \cdot s^{-1}$ = Metres per second

ms = Milliseconds

MDS = Maximal Dynamic Strength

MDP = Maximal Dynamic Power

MMA = Mixed Martial Arts

Na^+ = Sodium

NEAT = Non Exercise Activity Thermogenesis

O_2 = Oxygen

OG = Olympic Games

P1NP = Total Procollagen Type 1 N-Terminal Propeptide

Ph = Phosphate

POMS = Profile of Mood States

P_{osm} = Plasma Osmolality

PRO = Protein

PSS = Protector & Scoring System

PTH = Parathyroid Hormone

RDVAREA = Right Ventricular Diastolic Area

RED-S = Relative Energy Deficiency in Sports

RER = Respiratory Exchange Ratio

RMR = Resting Metabolic Rate

RMR_{meas} = Measured Resting Metabolic Rate

RMR_{pred} = Predicted Resting Metabolic Rate

RMR_{ratio} = Resting Metabolic Rate Ratio

RPE = Rating of Perceived Exertion

RSI = Reactive Strength Index

RVFAC = Right Ventricular Fractional Area Change

RWG = Rapid Weight Gain

RWL = Rapid Weight Loss

RWLQ = Rapid Weight Loss Questionnaire

RWLS = Rapid Weight Loss Score

s = Seconds

SEE = Standard Error of the Estimate

SHBG = Sex Hormone Binding Globulin

SJ = Squat Jump

SKf = Sum of Skinfolds

s-RPE = Session Ratings of Perceived Exertion

STCP-W = Simulated Taekwondo Competition Pad-Work Protocol

SWC = Smallest Worthwhile Change

T_3 = Triiodothyronine

T_4 = Thyroxine

T = Testosterone

TBW = Total Body Water

TC = Total Cholesterol

TEE = Total Energy Expenditure

TEF = Thermic Effect of Food

TG = Triglyceride

TMD = Total Mood Disturbance

TP = Total Protein

TRIAD = Female Athlete Triad

U = Urea

U_{osm} = Urine Osmolality

W = Watts

WAnT = Wingate Anaerobic Test

WDEB = Within Daily Energy Balance

WT/F = World Taekwondo (Federation)

List of Terms

Akimbo – *hands held on hips with elbows turned outwards*

Bandal Chagi – *Korean Romanisation of 'front kick'*

Basal Metabolism – *the energetic cost of physiological function during complete rest*

Bilateral – *a movement or exercise involving the use of both limbs simultaneously*

beats·min^{-1} – *heart rate in beats per minute*

Catch Weight – *common term when two fighters agree to compete at an agreed weight limit*

Clinch – *similar to boxing when two athletes come into close proximity and grapple or push each other*

Covering – *blocking a kicking technique i.e. covering the scoring area*

Cutting – *common combat sport term given to rapidly losing body mass in an acute timeframe*

Dollyo Chagi – *Korean Romanisation of 'turning kick'*

Ectomorph – *somatotype of long structure/stature with low lean mass and minimal fat mass*

Endomorph – *somatotype of short structure/stature with medium lean mass and high fat mass*

Fencing – *repeatedly using the front leg to kick against another opponent's front leg*

FAT$_{max}$ – *the maximal amount of fat oxidised during an incremental exercise test*

g·cm^{2} – *a measurement of density in bone mineral composition measured in grams per centimetre squared*

g·min^{-1} – *grams per minute*

Grappling – *a fighting discipline which can involve grabbing, throwing, pinning, locking and sweeping*

HR$_{max}$ – *maximal amount of heart rate in beats·min^{-1} during incrementally fatiguing exercise*

Judo – *a Japanese martial art which involves grappling and throwing techniques*

Judoka – *term for a Judo athlete*

Karate - *a Japanese martial art which involves punching, kicking, grappling and throwing techniques*

kg·BM^{-1} – *load measured relative to body mass*

kcal·LO$_2^{-1}$ – *kilocalories per litre of oxygen*

kcal·min^{-1} – *kilocalories per minute*

kcal·kgFFM·day^{-1} – *energy available in kilocalories relative to body mass per day*

km·hr^{-1} – *kilometres per hour*

L·hr^{-1} – *Litres per hour*

ml·kg·min^{-1} – *millilitres of oxygen relative to body mass per minute of exercise*

mmol·L^{-1} – *millimolars per litre of blood content*

Mesomorph – *somatotype of medium structure/stature with large lean mass and minimal fat mass*

mOsmols·kgH2O^{-1} – *measurement of osmolality in milliosmoles per kilogram of water*

Pankration – *an ancient Greek combat sport characterised by combinations of striking and grappling*

Periodised – *dependent sequential and integrated of periods time within a training programme*

Purse – *a common term to describe the remuneration paid to professional combat sport athletes*

Rapid Weight Loss – *term used to describe methods which are used to acutely lose body mass*

Repechage – *a system where the losers to competition finalists are given another chance to compete for third place positions*

Single Elimination – *where the loser of a contest is immediately eliminated from the competition*

Striking – *a fighting discipline which can involve punching, kicking, elbowing and kneeing*

U_{sg} – *a measure of the concentration of solutes in the urine measured in urine specific gravity*

µSv – *the energy absorbed by mass from ionising radiation measured in micro Sieverts*

$\dot{V}O_2$ – *the volume of oxygen uptake*

$\dot{V}O_{2max}$ – *maximal amount of oxygen uptake during incrementally fatiguing exercise*

$\dot{V}O_{2peak}$ – *peak amount of oxygen uptake during incrementally fatiguing exercise*

W – *a unit of power derived from 1 joule per second measured in watts*

W·kg^{-1} – *watts measured relative to body mass*

Water Loading – *disturbing body fluid/sodium equilibrium via euhydration to induce body mass loss*

Making Weight – *term used to describe the act of losing body mass for a specified weight target*

%HR$_{max}$ – *the percentage of maximum heart rate*

Σ_{SKf} – *the sum of skinfold measurement*

CHAPTER 1.

General Introduction

1.1. Background

Taekwondo is a martial art combat sport, noted for full contact kicking and punching striking actions and with the aim of winning via highest score or knockout. Taekwondo bouts (also referred to as contests or matches) are 3 x 2 minutes in duration with a 1 minute break and are contested across an individual day, with competitors having several bouts across either a *single elimination* or *repechage* format (Butios & Tasika, 2007). Given the full contact nature of bouts, Taekwondo competitors are classified into weight categories in order to promote fair competition between athletes of equal body mass (BM) (Kazemi et al., 2006). At World Taekwondo (WT) events, Senior athletes (>17 years) compete within 8 weight categories per sex with 4-7 kilogram (kg) differences, whereas at the Olympic Games (OG) and their respective qualification events, these categories are halved to 4 with >10 kg differences. This is also the case for Junior athletes (14-17 years) who compete in 10 weight categories per sex with 2-5 kg differences and at the Youth Olympic Games (YOG) these categories are also halved, with 5-10 kg differences. Male and female Cadet (12-14 years) athletes also compete in 10 weight categories with 4 kg differences but have no OG event (see Table 2.1 for all division categories) (World Taekwondo, 2018b). As such, this makes Taekwondo competitors unique amongst other combat sports, given both Junior and Senior athletes may be required to compete in two differing weight categories throughout their competitive season and/or careers.

Due to the variance between weight categories, there is widespread practice of losing BM (also known as *making weight* or *cutting*) within the sport (Fleming & Costarelli, 2007). There have been a number of studies conducted in small cohorts of Taekwondo athletes, examining the frequency, magnitude and occurrence of BM losses practises (Barley et al., 2017; Brito et al., 2012; da Silva Santos et al., 2016; Diniz et al., 2014; Dubnov-Raz et al., 2016; Fleming & Costarelli, 2009; Janiszewska & Przybyłowicz, 2015; Kazemi et al., 2011; Reale et al., 2018a). These investigations have demonstrated that Taekwondo athletes achieve their target weight category by a means of both chronic energy restriction/increased expenditure and acute (or commonly termed *rapid*) weight loss

(A/RWL) techniques, where in excess of 91% of athletes lose up towards 6% of BM. Whilst these studies prove useful to examine these practices, many were conducted out of season when the participants were not engaging in BM loss for competition. To understand the perceptions of making weight and the key influences on the motivation to engage in BM loss, it is vital to assess these practices *in situ*, with athletes of varying sexes/age divisions and explore any potential differences in behaviours between these groups. Additionally, it is important to highlight the magnitudes of BM reduction required in athletes, when competing in differing WT and OG weight categories, given the latter may require greater losses than have been previously characterised.

It is integral to examine both the influences and motivations of athletes who engage in BM loss for competition. The incentive to practice extreme BM loss regimens can often come from financial rewards, highlighted in professional athletes of sports such as horse racing (Caulfield & Karageorghis, 2008), boxing (Collins, 2014) and mixed martial arts (MMA) (Corner, 2017). In Olympic combat sports, financial incentive is not necessarily a factor and the main influences of BM loss often come from the deep rooted cultural inferences imposed by peers and coaches (Franchini et al., 2012). To that end, qualitative examination techniques may prove useful to further tease out the perceptions and motivations of key stakeholders involved in the making weight culture of combat sports, given the open ended nature of their enquiry. Two studies have utilised qualitative research techniques to explore specific themes in detail, highlighting factors related to physique and also self-actualisation via mental advantage as being important in the decision to engage in these practices, congruent with any advantages gained in physicality (Pettersson et al., 2013; Pettersson et al., 2012). Despite these findings, there is still a disparity in the research, given that coaches have been identified as an important stakeholder in the process of influencing BM loss practices within this demographic and this deserves further exploration. It is also equally important to consider that Taekwondo athletes under the age of legal responsibility could also have additional confounding environmental factors, which may encourage these practices and behaviours, inclusive of those found on social media and through parental relationships (Field et al., 2001; Sansone & Sawyer, 2005; Weissinger et al., 1991).

In line with making weight practices, behaviours and influences, it is vitally important to understand the impact these may have on overall athlete health and performance. Protracted energetic deficits, concomitant with acute dehydration may heighten the risk of infections (Tsai et al., 2011a; Tsai et al., 2011b), have a negative influence on psychological status (Degoutte et al., 2006; Hall & Lane, 2001) and even cause severe injury or death due to increased cardiovascular and thermoregulatory demands (AP News, 1996; Centers for Disease Control and Prevention, 1998; Fernandez, 2015; MasTKD, 2018). To maintain adequate health, it is key for Taekwondo athletes to compete in the most appropriate weight category in relation to lean mass (LM) and optimise power to mass ratio for Taekwondo competition. To that end, the loss of fat mass (FM) to maintain a low FM percentage (FM%), with minimal disruption to LM, can therefore be regarded as the most efficient way to reduce whole BM (Langan-Evans et al., 2011).

To examine these tissues and assess the potential for an athlete to make a specified weight category, an assessment of body composition utilising the most valid, accurate and reliable equipment possible is often prescribed. Multi-compartmental measures such as Dual X-ray Absorptiometry (DXA) are widely regarded as the criterion method in athletic populations, given the ability to assess both whole body and regionalised indices of bone mineral content/density (BMC/D) alongside LM and FM (Reilly et al., 2009). Three studies have examined a Taekwondo demographic with this technique (Reale, 2017; Seo et al., 2015; Ubeda et al., 2010), with the largest scope of body composition examinations being conducted utilising sum of skinfolds ($\sum_{SKf}$) and subsequent prediction equations (Bouhlel et al., 2006; Chiodo et al., 2011; Fleming & Costarelli, 2007; Fritzsche & Raschka, 2008; Ghorbanzadeh et al., 2011; Heller et al., 1998; Markovic et al., 2005; Markovic et al., 2008; Mashhadi et al., 2013; Rahmani-Nia et al., 2007; Rivera et al., 1998). Given many of these investigations have employed a whole range of varying $\sum_{SKf}$ and prediction equations, conducted at a number of conflicting time points, there is a clear need for examinations of body composition in Taekwondo athletes utilising both DXA and $\sum_{SKf.}$ Not only is this important to highlight both the whole body and regional indices of LM and FM during BM loss, but also the most relevant prediction equations, which can be employed accurately when other techniques may not be available in practice.

BM loss via the manipulation of the aforementioned tissues, can be achieved by creating a deficit in energy balance (EB), where energy intake (EI) is lower than total energy expenditure (TEE) and this can be manifested by either a decrease in nutritional intake and/or an increase in energetic expenditure through activity/exercise (AEE) (Langan-Evans et al., 2011). Loucks (2004) has proposed that rather than EB, energy availability (EA) should be examined during BM reduction, which is calculated via the assessment of EI minus AEE to generate a kilocalorie (kcal) value per kg of fat free mass (FFM) per day. Loucks et al. (2011) postulate that EB equates to an EA of 45 $kcal{\cdot}kgFFM{\cdot}day^{-1}$ with a minimum threshold of 30 $\mathrm{kcal{\cdot}kgFFM{\cdot}day^{-1}}$ as a target for healthy and effective BM losses. EA below this level, categorised as low energy availability (LEA), is proposed to be deleterious to both health and performance in not meeting the required energy surplus to support essential metabolic and physiological functioning (Logue et al., 2018). To assess EA status, it is paramount that valid, accurate and reliable measurements of both EI and AEE are utilised to make inferences about the potential for LEA (Burke et al., 2018b). The accurate examination of EI can be regarded as one of the most difficult measurements in sport and exercise science given the potential for error in the assessment method, participant engagement and researcher analysis (Hackett, 2009). Few studies have examined EI in Taekwondo athletes and are either inclusive (Fleming & Costarelli, 2007; Papadopoulou et al., 2017) or non-inclusive (Cho, 2014; Cho et al., 2013; Rossi et al., 2009) of BM loss engagement.

AEE is as equally difficult to measure both validly and accurately in athletic populations, given the variability in assessment techniques (Ndahimana & Kim, 2017). Whilst methods such as direct calorimetry and doubly labelled water (DLW) are regarded as the criterion standard in the assessment of TEE, they are often too expensive to employ in both research and practice, given they are unable to detect AEE in independently limited timeframes. Therefore, indirect calorimetry measurement methods are often utilised, examining O_2/CO_2 gaseous exchange for the estimation of heat production during aerobic metabolism. Some studies have utilised this method in Taekwondo activities (Toskovic et al., 2002) and competition simulations (Campos et al., 2012; Lopes-Silva et al., 2018; Lopes-Silva et al., 2015; Yang et al., 2018) to produce estimates of AEE, however, this is unfeasible in contact based actions with high ecological validity. The use of portable actigraphy is becoming more popular when examining AEE in a host of activities (Shephard & Aoyagi, 2012) and while more common in general populations, there are an increasing number of investigations instigating its use in athletic demographics across a range of sports (Bradley et al., 2015; Brown et al., 2017; Dieu et al., 2014; Walker et al., 2016; Yoshida et al., 2018). A limited number of studies have utilised portable actigraphy with Taekwondo athletes (Cho, 2014; Cho et al., 2013) and given the need to assess AEE practically yet validly, accurately and reliably in this population for inferences of potential LEA during BM loss, further investigation of its use during Taekwondo based training and competition activities is warranted.

The psychological and physiological performance consequences of LEA have been characterised as relative energy deficiency in sports (RED-S) in the seminal IOC consensus statements by Mountjoy et al. (2014) and updated by Mountjoy et al. (2018). The current threshold of LEA leading to RED-S syndromes was generated from a number of studies conducted in females and therefore may be too high for males with reduced reproductive physiological and metabolic functioning. A review by Fagerberg (2018), surveying LEA with a focus on male bodybuilders, has shown this hypothesis may hold true as it appears the negative effects of LEA via RED-S may only manifest at a threshold below 20-25 kcal·kgFFM·day^{-1}. To date no specific investigation of LEA leading to potential RED-S outcomes has ever been performed in a Taekwondo athlete demographic. However, as described previously, it is often a requirement for Taekwondo athletes to engage in transient periods of chronic energy deficit coupled with A/RWL techniques to be able to meet a target weight category, which may result in LEA (Burke et al., 2018a). On this basis, there is scope to conduct an examination of the effects of prolonged LEA, combined with A/RWL practices on the psychological, physiological and metabolic health of Taekwondo athletes undertaking BM loss for competition.

1.2. Aims, Objectives and Structure of Thesis

The overall aim of this thesis is examine the psychological and physiological health and performance consequences of making weight in international standard Taekwondo athletes. This will be achieved via a number of objectives, which will be co-ordinated utilising the Applied Research Model for the Sport Sciences (ARMSS) by Bishop (2008). The ARMSS process, as highlighted in Figure 1.1, employs eight key stages following a system of description and experimentation prior to final implementation, in consideration of research design for application in real world sport settings.

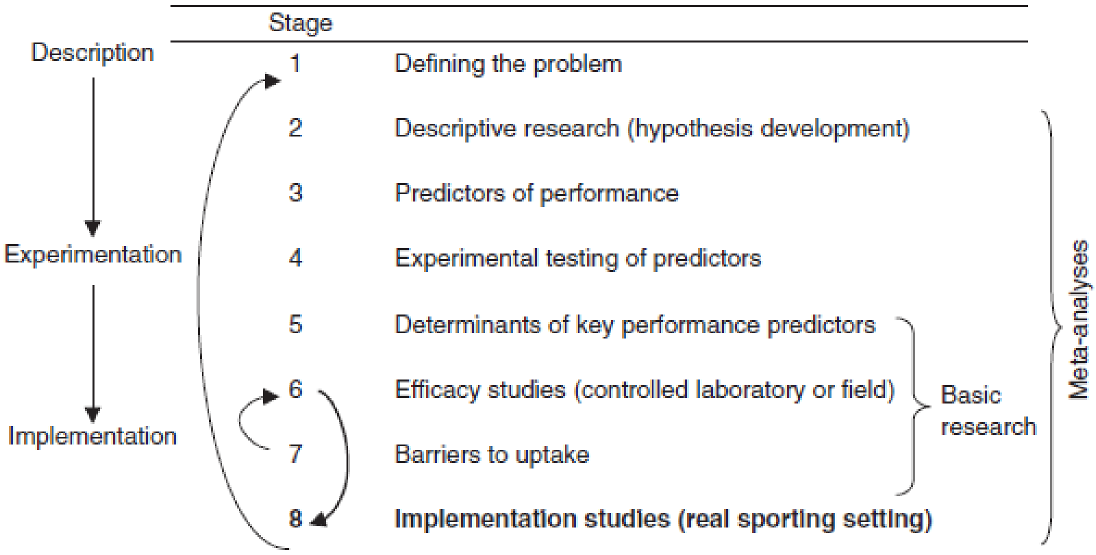


Figure 1.1: *An Applied Research Model for the Sport Sciences as proposed by Bishop (2008).*

Initially, this thesis will investigate the frequency, occurrence and magnitude of BM losses and influences on the decision to engage in these practices, in athletes of differing sexes and age divisions (Description: Stages 1 and 2 – *definition of the problem and descriptive research for hypothesis generation*). Following this, an evaluation of the most valid, accurate and reliable assessments of both body composition and AEE in an ecologically valid setting will be employed as a means to examine and/or aid the findings of objective one (Experimentation: Stages 4 and 6 – *experimentation of performance predictors and efficacy studies within controlled settings*). Finally, the thesis will assess how a chronic period of energetic deficit, coupled with the use of A/RWL techniques, may impact on the potential for symptoms of RED-S consequences when employing a periodised nutritional and training programme (Implementation: Stage 8 – *implementation within a real world sporting setting*).

This aim will be achieved by the completion of the following objectives in the form of the following studies:

1. Assess the frequency, occurrence and magnitude of BM loss in international standard Taekwondo athletes *in situ* and examine potential differences between sexes, age divisions and WT/OG categories. (**Study 1**).
2. Analyse the ergogenic dietary supplements utilised by these athletes, to support making weight and performance practices in tandem with knowledge of use and anti-doping histories (**Study 1**).
3. Explore stakeholder perceptions (as identified in Study 1) of the influences which encourage the engagement in these practices and behaviours inclusive of nutritional and ergogenic dietary supplement knowledge (**Study 2**).
4. Evaluate the body composition indices of international standard Taekwondo athletes and absolute BM losses when required to make weight for OG or WT categories (**Study 3**).
5. Determine the validity and accuracy of commonly utilised field based body compositional measures ($\sum_{SKf}$) in comparison with criterion laboratory equipment (DXA) (**Study 3**).
6. Design and assess the efficacy of an ecologically valid laboratory protocol, which mimics the physiological demand of Taekwondo competitive activities (**Study 4**).
7. Establish the validity and accuracy of field based and criterion measurements of AEE during use in an ecologically valid laboratory protocol (**Study 4**).
8. Examine the effect of a periodised nutritional and training intervention on symptoms of RED-S consequences while making weight for competition (**Study 5**).

CHAPTER 2.

Literature Review

2.1. Taekwondo

2.1.1. Development into a Modern Olympic Sport

Taekwondo is a 2000 year old combat martial art and Olympic sport, which promotes self-defence via a variety of blocking, kicking and punching techniques and is the national sport of South Korea. At the 1988 Seoul and 1992 Barcelona Olympic Games, Taekwondo was officially programmed as a demonstration sport and through this inclusion, gained global appeal with many national federations being formed throughout the world. Taekwondo was officially recognised as an Olympic sport on 4th September 1994 at the 103rd IOC Session in Paris, France and was included an official event in the programme of the 2000 Sydney Olympic Games (World Taekwondo, 2018b). Since the 2000 Games, Taekwondo has successfully participated within another 4 Olympic programmes culminating in the 2016 Rio Olympic Games held in Brazil. Throughout this period Taekwondo has undergone a series of rule changes that would not only influence the way the sport was competed, but also the habits and characteristics of the athletes who participate.

2.1.2. Current Rules and Regulations

The evolution of the rules in Taekwondo, have been increasingly dramatic since the sports inclusion in the Olympic programme. A more in depth discussion regarding the development of weight categories within the sport is addressed in section 2.5 of this literature review. Weight categories for WT and OG Senior (>17 years), Junior (14-17 years) and Cadet (12-14 years) divisions are characterised in Table 2.1. For each weight category competitors must be over their targeted weight and not exceed the weight above i.e. over 54 kg not exceeding 58 kg.

Table 2.1: *Current OG/WT weight categories in Taekwondo competitions*

SENIOR	**WT Male**	**WT Female**	**OG Male**	**OG Female**
Fin	-54 kg	-46 kg		
Fly	-58 kg	-49 kg	-58 kg	-49 kg
Bantam	-63 kg	-53 kg		
Feather	-68 kg	-57 kg	-68 kg	-57 kg
Light	-74 kg	-62 kg		
Welter	-80 kg	-67 kg	-80 kg	-67 kg
Middle	-87 kg	-73 kg		
Heavy	+87 kg	+73 kg	+80 kg	+67 kg
JUNIOR	**WT Male**	**WT Female**	**OG Male**	**OG Female**
Fin	-45 kg	-42 kg		
Fly	-48 kg	-44kg	-48 kg	-44kg
Bantam	-51 kg	-46 kg		
Feather	-55 kg	-49 kg	-55 kg	-49 kg
Light	-59 kg	-52 kg		
Welter	-63 kg	-55 kg	-63 kg	-55 kg
Light Middle	-68 kg	-59 kg		
Middle	-73kg	-63 kg	-73kg	-63kg
Light Heavy	-78 kg	- 68 kg		
Heavy	+78 kg	+68 kg	+73 kg	+63kg
CADET	**WT Male**	**WT Female**		
Fin	-33 kg	-29 kg		
Fly	-37 kg	-33 kg		
Bantam	-41 kg	-37 kg		
Feather	-45 kg	-41 kg		
Light	-49 kg	-44 kg		
Welter	-53 kg	-47 kg		
Light Middle	-57 kg	-51 kg		
Middle	-61 kg	-55 kg		
Light Heavy	-65 kg	-59 kg		
Heavy	+65 kg	+59 kg		

Across 27 years from the creation of the World Taekwondo Federation (WTF) in 1973, to the sports inaugural participation in the Sydney 2000 Games, the rules were amended a total of 8 times. However, since that time in the last 18 years, the rules have been amended 17 times including major changes to competitive areas, contest times and penalties as highlighted in changes to prohibited acts in Table 2.2 (World Taekwondo, 2018b).

Table 2.2: *Taekwondo competition prohibited acts pre and post 2000 Olympic Games*

Pre 2000 Olympic Games	Post 2000 Olympic Games
1. Avoiding or delaying* the contest 2. Grabbing, holding or pushing** the opponent 3. Kicking below the waist 4. Hitting the opponents head with the hand 5. Butting or attacking with the knee 6. Attacking a fallen opponent 7. Misconduct on behalf of the contestant or coach	8. **Crossing the boundary line** 9. **Falling down** 10. **Lifting the knee to block or/and impede an opponent's kicking attack** 11. **Lifting the leg for longer than 3 seconds to impede the opponents attack or movements** 12. **Attacking the opponent after *kalyeo***

*includes a 5 second inactivity ruling if neither one or both of the athletes is engaging in the contest – rule change introduced in 2013

**pushing was legalised in rule changes introduced in 2017 – athletes are now allowed to push opponents in a *clinch* but are still prohibited from grabbing and holding

Additionally, since 2008 the introduction of Protector and Scoring Systems (PSS) have dramatically altered the way bouts are contested. The development of PSS determined that blocking (also termed as *covering*) became a crucial part of competition strategy. As a direct result of this, the amount of points which are awarded for different scoring techniques, have dramatically evolved over time. Prior to 2002, all points which scored to either the body or the head were awarded one point, so many athletes would make a conscious choice not to try and score a more technically difficult head kick, unless aiming to achieve a knockout blow. After considerable amendments and as of 2018, the valid point rules were established as 1 point being awarded for a punch to the trunk protector, 2 points for a kick to the trunk protector and 3 points for a head kick, with trunk protector and head ‘spinning’ kicks earning 4 and 5 points respectively. Another revolutionary change within the sport introduced post 2008 Beijing Olympic Games, was an Instant Video Replay system (IVR), which reviews the appeal of scores and decisions made during contests. Since the introduction of PSS and IVR systems, the sport has developed into an increasingly front leg dominated style, where athletes will *fence* with their legs in order to score. The previously antiquated style of play, including spinning and double kicking techniques are all but obsolete, due to the greater amount of penalties i.e. for falling down, smaller ring sizes etc. where there is less room to manoeuvre and via covering of techniques from scoring. In line with this there has also been an evolution in the physical and physiological characteristics of Taekwondo athletes and this will be addressed in the next three sections of this literature review.

2.2. Taekwondo Athlete Anthropometrical Characteristics

In parallel to the rapid development of the rules across many years, there has been a consistent evolution in the anthropometrical profile of Taekwondo athletes (Kazemi et al., 2014). Within anthropometry, the examination of body composition to the explore the specific structures of the human body can be considered in both a variety of sections and compartments (Langan-Evans et al., 2019). Wang et al. (1992) characterise sections into atomic, molecular, cellular, tissue/system and whole body analyses. Exploration of the changes that occur at these differing sections are often compartmentalised dependant on the measurement method used (e.g. a whole body measurement could be assessed in a single compartment i.e. stature) and are generally divided into either two (FM; FFM), three (FM; LM; BMC) or multi-compartmental assessment using a combination of measurement techniques (i.e. FM; LM; BMC; Total Body Water [TBW]) (Langan-Evans et al., 2019).

The exploration of sections and compartments can be conducted via a number of measurement tools, based on three levels of validation hierarchy (Eston & Reilly, 2009). Level one methods are classified as any direct measurement (i.e. stature, BM), whereas level two are indirect and subsequent estimation allows a calculation of tissues to be established. Level three are doubly indirect methods, conducted utilising a level two measurement, then an estimation of body density established and converted to a FM% using a prediction equation. Level two methods are heavily reliant on the standardisation of their protocols to enhance accuracy of measurement, as do level three methods with an additional confounding variable, generally based on highly sample specific equations i.e. sex, ethnicity, training status etc. Needless to say however, the valid, accurate and reliable measurement of body composition can still be regarded as one of the most challenging fields of anthropometry. The research examined in this section will fundamentally highlight both tissues/systems and whole body sections, focussing particularly on FM (also coined as adipose tissue/body fat), FFM/LM (also coined as lean muscle tissue/mass), somatotype and stature measurement conducted on international standard Taekwondo athletes throughout the literature.

2.2.1. Tissue/System – Fat Mass and Fat Free/Lean Mass

Due to the weight category mediation of the sport, it is hypothesized that the requirement for optimal power to mass ratio is desirable for Taekwondo athletes (Reale et al., 2017b). A review by Bridge et al. (2014) conducted across a number of academic search engines (PubMed, ISI Web of Knowledge, Google Scholar, SportDiscus® and Scopus) from inception to March 2013, highlighted 45 research articles, which had examined body composition in international, national and novice Taekwondo athletes across both male (24 articles) and female (21 articles) demographics. The results of these studies indicated that international standard Taekwondo athletes demonstrate low levels of FM, with ranges of 7-14% in males and 12-19% in females, respectively. Unsurprisingly, national and novice Taekwondo athletes were found to have higher FM% than their international counterparts, although the results from many of these studies are conflicting and further research is required to elucidate stronger evidence of this trend. An additional interesting observation of the review, is that Junior Taekwondo athletes were found to have higher FM levels than their Senior counterparts, with percentage ranges of 11.0-14.1% in males and 19.5-24.0% in females. Bridge et al. (2014) hypothesize that this may be due to a potential reduced emphasis of BM loss practices or due to differences in overall training volumes in this population.

Since March 2013 there have been a number of research articles, which have examined FM of international standard male and female Taekwondo athletes, although this is often not the principle research question (Chen et al., 2017; Kim et al., 2015; Mashhadi et al., 2013; Reale, 2017; Rhyu & Cho, 2014; Rhyu et al., 2014; Seo et al., 2015). Based on all of the aforementioned research studies the mean FM of international standard Taekwondo athletes are represented as 10% in males and 15% in females collectively. Bridge et al. (2014) state that to the best of their knowledge no research study has tried to identify body composition tissues of Taekwondo athletes in differing weight categories and this still holds true currently. As such, there may be an optimal body composition for Taekwondo athletes mediated by weight category and further research is warranted to establish this information.

What is clear from the literature, is that the methods examining body composition in Taekwondo athletes are diverse. The majority of the studies in international standard athletes, have been conducted using sum of skinfold ($\sum_{SKf}$) methodology and subsequent FM% calculation equations (Bouhlel et al., 2006; Chiodo et al., 2011; Fleming & Costarelli, 2009; Fritzsche & Raschka, 2008; Ghorbanzadeh et al., 2011; Heller et al., 1998; Markovic et al., 2005; Markovic et al., 2008; Mashhadi et al., 2013; Olds & Kang, 2000; Pieter & Taaffe, 1990; Rahmani-Nia et al., 2007; Rivera et al., 1998; Taaffe & Pieter, 1990). To date, only nine studies have been conducted utilising bioelectrical impedance analysis (BIA) (Chen et al., 2017; Cho, 2014; Cho et al., 2013; Fritzsche & Raschka, 2008; Kim et al., 2015; Rhyu & Cho, 2014; Rhyu et al., 2014; Tsai et al., 2011a; Tsai et al., 2011b) with only three studies investigating body composition employing DXA (Reale, 2017; Seo et al., 2015; Ubeda et al., 2010). Further to this, there is a paucity of data examining the LM and BMC/D of international standard Taekwondo athletes utilising measures of both BIA and DXA, with only five studies (Cho, 2014; Cho et al., 2013; Reale, 2017; Rhyu & Cho, 2014; Seo et al., 2015) providing indices of whole body LM in males (BM: 64.1-73.3 kg - LM: 54.7-58.9 kg) and females (BM: 59.8-60.6 kg - LM: 43.6-43.9 kg), from which two of these studies provide whole body measures of BMC/D in males (BM: 67.6-69.8 kg - BMC: 3.0-3.5 kg - BMD: 1.29 $g \cdot cm^2$) and females (BM: 59.8-60.6 kg – BMC: 2.7-2.8 kg – BMD: 1.21 $g \cdot cm^2$).

As a two compartmental doubly indirect assessment tool, anthropometric $\sum_{SKf}$ measurement is applied via the use of a calliper to a double fold of gripped skin (Martin et al., 1985). Bridge et al. (2014) state that whilst the use of $\sum_{SKf}$ and subsequent prediction equations are popular in examining the body composition tissues of international Taekwondo athletes, this is often motivated by ease of use and accessibility. Therefore, the data generated from research studies conducted in Taekwondo athletes utilising this technique should be interpreted with caution. Given the inaccuracies manifested in FM measurement produced via predictive $\sum_{SKf}$ equations, there has been a petition to focus solely on the use the $\sum_{SKf}$ (often 8 sites) as this can be a far more reliable and sensitive indicator of body compositional change over time (Johnston, 1982; Reilly et al., 1996).

As another doubly indirect but multi-compartmental 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). As LM contains both intra (ICW) and extracellular (ECW) water/fluid, electrical current flow is able to pass freely, whereas in non-conducting tissues i.e. FM and BMC conductivity is reduced. There have been a number of studies showing that the reliability of BIA is reduced when nutritional (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. In all of the aforementioned Taekwondo body composition examinations employing BIA, none discuss standardising these pre assessment factors in their respective methodologies, other than the study by Chen et al. (2017), so the results of these studies should again be interpreted with caution.

DXA is a three compartmental indirect method and an in depth review of the technical aspects of its use have been published by Bazzocchi et al. (2016). There is a dose of radiation delivered during the measurement, which amounts to around 2-10 μSv dependant on the make, model and type of scan being utilised. In context, this is equal to only one day of annual natural background radiation experienced in normal living, or is the equivalent to eating 100 g of brazil nuts or five bananas. However despite this, the awareness of both legal and ethical constraints must be considered prior to measurement with DXA in athletic populations, which limit the frequency of its use. There have been a number of standardisation issues, which highlight reduced reliability in DXA measurement including pre scan nutritional (Bone et al., 2016), hydration (Toomey et al., 2017) and exercise (Nana et al., 2012) statuses and this has led to the development of a best practice protocol (Nana et al., 2016; Nana et al., 2015). Of the three body composition studies utilising DXA in international Taekwondo athletes only Reale (2017) employed this protocol and despite any limitations, DXA is still often regarded as the criterion standard of body tissue measurement (Bazzocchi et al., 2016), which may provide the best insight into the body composition of international Taekwondo athletes in future investigations.

2.2.2. Whole Body – Somatotype and Stature

Bridge et al. (2014) highlights only 15 research articles examining the somatotype profile of both male (9 articles) and female (6 articles) demographics in international, national and novice standard Taekwondo athletes. In the majority of these studies, international standard Taekwondo athletes exhibited a predisposition of *mesomorphy,* with males predominantly displaying an ectomorph mesomorph and females a mesomorph ectomorph somatotype profile. Whilst female athletes display overall higher *endomorphic* characteristics and Junior male Taekwondo athletes a greater mesomorph *ectomorph* profile, in contrast to their Senior counterparts, this is unsurprising due to higher FM in females and lower levels of LM due to maturation status in younger athletes (Malina & Geithner, 2011). A point of interest is that the majority of the studies included in this review were conducted prior to the 2008 Beijing Olympic Games and given the previous high contact and explosive power demand of the sport, many Taekwondo athletes were relatively shorter with greater amounts of FFM than their modern day competitive counter parts (Olds & Kang, 2000; Taaffe & Pieter, 1990). A study by Kazemi et al. (2014) examining the differences between Taekwondo competitors in the 2000 to 2012 editions of the Olympic Games, has highlighted that stature in all weight categories and across sexes has increased by up to 10 centimetres (cm). Figure 2.1 demonstrates the mean stature of Taekwondo competitors in the last five editions of the Olympic Games, where the largest differences are exhibited in the lighter weight categories, with smaller differences between the competitors in the heavier weight categories.

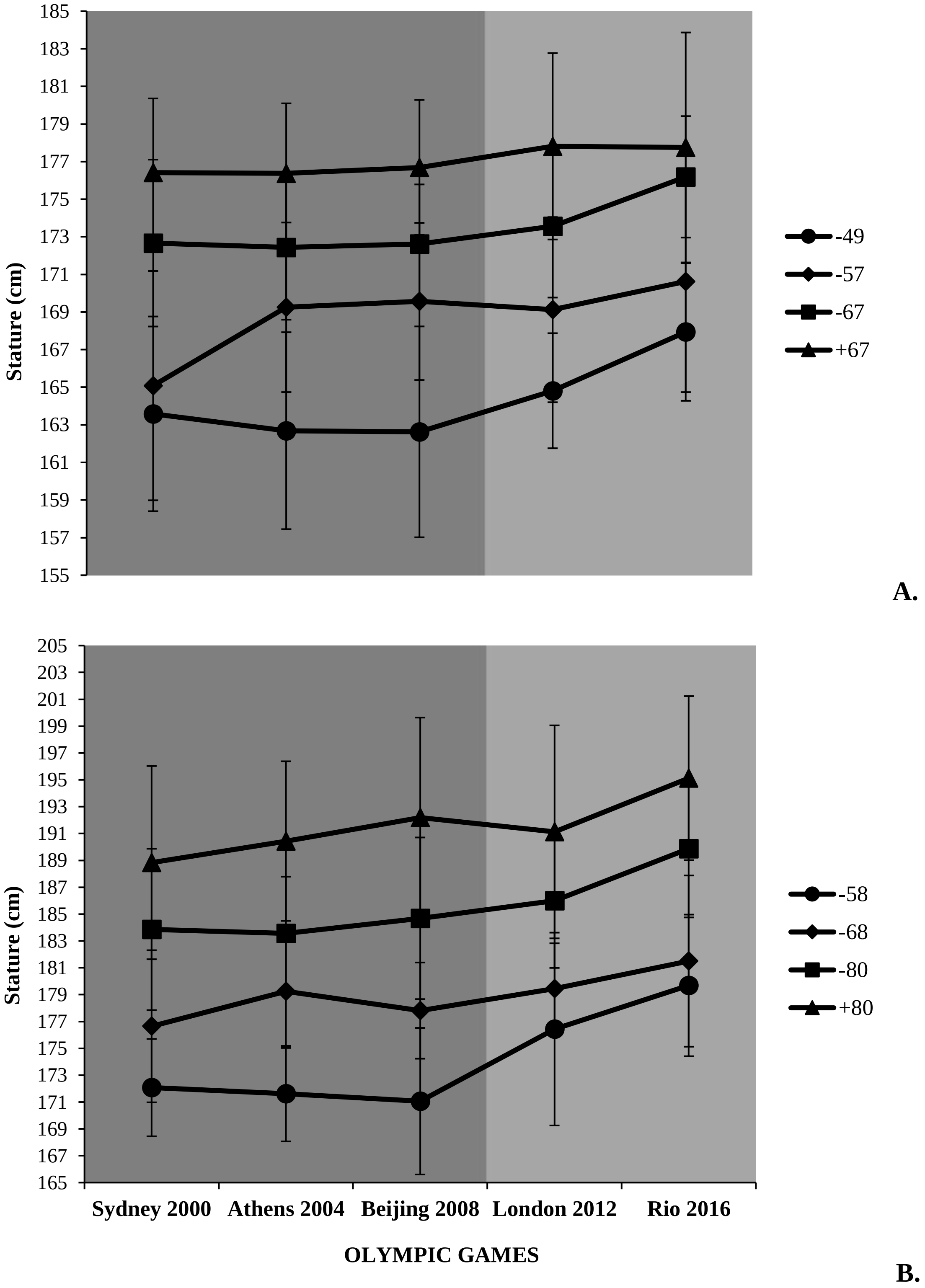


Figure 2.1: *Comparison of the mean stature of female (A.) and male (B.) Taekwondo competitors across the 2000-2016 editions of the Olympic Games (dark grey area denotes events pre PSS and significant rule changes).*

Studies in international Taekwondo athletes post 2008 Olympic Games (and since the introduction of PSS), have demonstrated that concomitant with increases in stature, an evolution of somatotype profiles which exhibit greater ectomorphy and decreasing traits of mesomorphy (Ghorbanzadeh et al., 2011). Noh et al. (2013) examined differences in the somatotype of differing male Olympic weight categories and found that lighter weight categories (fly -58 kg and feather -68 kg), had a higher predominance of ectomorphy over their heavier counterparts (welter -80 kg and heavy +80 kg). These finding were also supported in a study Jung et al. (2015), who found greater levels of mesomorphy in the welter and heavy categories, in contrast to higher levels of ectomorphy in the fly and feather categories. The results of these studies and the increasing prevalence of an ectomorphic somatotype show a strong relationship with the increasing stature of international standard Taekwondo athletes across the Olympic Games programmes.

Whilst neither stature or somatotype profile are by no means a precursor to unparalleled success in the sport, many coaches are now including these factors as an essential component for selection of athletes in national team and talent identification/transfer programmes. As there was less emphasis in kicking to the head in previous versions of the rules, athletes who were considered to have a higher power to mass ratio than their opponents, were deemed to have a greater competitive advantage (Kazemi et al., 2014). However, since the introduction of the PSS scoring systems and with an increased emphasis to score to the head (Jae-Ok & Voaklander, 2016), taller athletes are now deemed to have a competitive advantage over smaller counterparts with greater reach in limb length.

There is a clear need for more research studies examining the changing anthropometric profiles of international Taekwondo athletes over subsequent Olympic Games programmes. This would need to be achieved utilising valid and reliable methods of examining body composition for indices of both whole body and regional FM, LM and BMC/D and a population specific prediction equation, which would allow a greater level of accuracy in anthropometric $\sum_{SKf}$ assessment.

2.3. Taekwondo Athlete Physical/Physiological Profile

Athletic performance in the sport of Taekwondo is mediated by a number of collective factors such as technical/tactical ability, psychological robustness and physical/physiological profile (Bridge et al., 2014). Taekwondo athletes require a high degree of both speed and agility physical qualities, in order to avoid the attacking or counter actions of their opponent (Sadowski et al., 2012). Due to a prominent emphasis in kicking to the head, there is an elevated demand for lower limb flexibility, concomitant with the ability to generate high force and velocity for power in striking actions with both maximal isometric strength (for pushing opponents in a *clinch*) and strength endurance (to hold lower limbs in high kicking positions) (Ball et al., 2011). Given the intermittent nature of the sport, there is a high contribution of all three energy system pathways (Campos et al., 2012; Hausen et al., 2017), where Taekwondo athletes are required to have well developed aerobic and anaerobic cardiorespiratory systems. The following sections will highlight both laboratory and field based measurements examining physical and physiological profiles of international standard Taekwondo athletes, with particular focus on strength/power and cardiorespiratory capabilities.

2.3.1. Strength and Power

To date, there have only been two studies (one in males/two in females and exclusively in Senior division athletes) examining maximal dynamic strength (MDS) in an international standard Taekwondo athlete population, conducted using whole body upper and lower *bilateral* loaded movements. Markovic et al. (2005) investigated the fitness profile of international standard female Taekwondo athletes, who displayed mean upper body 1 repetition maximum (RM) strength in the bench press movement of 55.7 ± 11.6 kg and lower body 1RM strength in the squat movement of 89.1 ± 17.6 kg. Relatively, this represented a $kg \cdot BM^{-1}$ score of 0.9 ± 0.1 and 1.4 ± 0.2 in the upper and lower extremities, respectively. Ball et al. (2011) also conducted 3RM strength assessments in 4 Taekwondo athletes selected for the Australian Olympic Team representing at the 2008 Beijing Olympic Games, who displayed mean upper body 3RM strength in the bench press movement of 56 ± 12 kg and lower body in the squat movement of 88 ± 3 kg. Similarly to the study by Markovic and colleagues, this represented relative kg·BM^{-1} scores of 0.9 ± 0.1 and 1.3 ± 0.1 in both the upper and lower extremities. Based on the relative scores in both these studies, this categorises international standard Taekwondo athletes within the 20th to 10th percentiles of normative values within a general population (Hoffman, 2006) and substantially lower than absolute scores measured in other striking (Chaabene et al., 2012) and grappling (Chaabene et al., 2017; Franchini et al., 2011) combat sports.

The assessment of lower limb maximal dynamic power (MDP), has been exclusively examined in Taekwondo athletes utilising jump based testing modalities. The majority of these studies have been conducted with a variety of differing measurement tools including jump and reach sticks, force platforms, linear encoders, electronic pressure and optical acquisition systems. There is also a large disparity between test standardisation, with some studies using vertical vs. horizontal jumps, with and without use of the arms and standing vs. running jumps. Table 2.3 highlights all studies, which have been conducted using either vertical countermovement (CMJ) and/or squat (SJ) jumps with standardised procedures, including fixed *akimbo* hand positions. Those studies which have used both CMJ and SJ, have then had the division of these values calculated to generate the eccentric utilisation ratio (EUR), which is used to observe the efficiency of muscular stretch shortening cycle capability (McGuigan et al., 2006).

It is clear from the presented literature that there is a considerable need for more data examining both the MDS and lower limb MDP capabilities of international standard Taekwondo athletes. Bridge et al. (2014) state that further research is needed to establish age division, sex and weight category differences, in line with the development of a standardised battery of tests to examine these variables and that consideration should be given to develop specialised and sport specific tests of lower limb muscular power.

Table 2.3: *Vertical jump scores for international standard male and female Taekwondo athletes (data are presented as mean ± SD).*

		MALE			FEMALE		
Reference	**Test Method**	**CMJ (cm)**	**SJ (cm)**	**EUR (au)**	**CMJ (cm)**	**SJ (cm)**	**EUR (au)**
Chiodo et al., 2011	OAS	40.8 ± 4.9	-	-	28.2 ± 2.5	-	-
Ghorbanzadeh et al., 2011	Not Specified	39.0 ± 5.5	-	-	27.5 ± 3.7	-	-
Markovic et al., 2005	EJM	-	-	-	32.8 ± 3.9	29.8 ± 2.9	1.10
Heller et al., 1998	FP	-	45.4 ± 4.5	-	-	29.8 ± 4.0	-
Casolino et al., 2012	OAS	41.0 ± 5.6	38.4 ± 6.0	1.07	27.4 ± 2.8	25.5 ± 3.7	1.07

		COMBINED SEX		
		CMJ (cm)	**SJ (cm)**	**EUR (au)**
Ball et al. 2011	OAS	43.0 ± 0.7	-	-
Cetin et al., 2009	LE	47.2 ± 6.4	43.5 ± 6.2	1.08
Chaabene et al., 2017	FP	40.2 ± 5.4	38.2 ± 4.6	1.05

OAS – Optical Acquisition System; EJM – Electronic Jump Mat; FP – Force Platform; LE – Linear Encoder; au – arbitrary units

2.3.2. Anaerobic and Aerobic Profiles

Taekwondo competition places a high demand on both of the anaerobic and aerobic pathways and Taekwondo practitioners require highly developed cardiorespiratory systems (Bridge et al., 2009). Numerous studies have examined these variables in international standard Taekwondo athletes, with the most common assessment of anaerobic profile, conducted via lower limb 30 second Wingate anaerobic testing (WAnT) for the measurement of relative peak power capacity and aerobic profiles conducted via $\dot{V}O_{2max}$ testing for the measurement of maximal oxygen uptake (Bridge et al., 2014).

Table 2.4 presents lower limb 30 second WAnT scores for international standard male and female Taekwondo athletes, with relative peak power represented as 8.4–14.7 $W{\cdot}kg^{-1}$ for males and 6.6–10.2 $\mathrm{W{\cdot}kg^{-1}}$ for females, respectively. These scores contrast positively with those from both other striking (Chaabene et al., 2012) and grappling (Chaabene et al., 2017; Franchini et al., 2011) combat sports plus normative values for power trained males (Coppin et al., 2012) and females (Baker et al., 2011).

Table 2.4: *Lower limb 30 second WAnT scores for international standard male and female Taekwondo athletes (data are presented as mean ± SD).*

		MALE				**FEMALE**			
Reference	**Test Method**	**Peak Power (W)**	**Peak Power (W·kg^{-1})**	**Mean Power (W)**	**Mean Power (W·kg^{-1})**	**Peak Power (W)**	**Peak Power (W·kg^{-1})**	**Mean Power (W)**	**Mean Power (W·kg^{-1})**
Taaffe & Pieter, 1990	load: 0.075 kp·kg^{-1}	864.6 ± 246.2	11.8 ± 2.0	671.2 ± 151.3	9.2 ± 1.2	621.4 ± 145.4	10.2 ± 2.5	481.9 ± 77.2	7.9 ± 1.2
Heller et al., 1998	load 5-6 W·kg^{-1}	-	14.7 ± 1.3	-	-	-	10.1 ± 1.2		
Lin et al., 2006	0.075-0.1 kp·kg^{-1}	-	8.4 ± 0.9	-	6.6 ± 0.6	-	6.6 ± 0.4	-	5.5 ± 0.9
Cetin et al., 2009	load: 0.075 kp·kg^{-1}	-	9.5 ± 1.5	-	7.2 ± 1.0	-	-	-	-
Sadowski et al., 2012	load NR	-	9.9 ± 1.0	-	-	-	-	-	-
Taskin & Akkoyunlu, 2016	load NR	-	-	-	-	442.4 ± 74.4	7.5 ± 0.8	337.2 ± 48.2	5.7 ± 0.5
Rocha et al., 2016	load: 0.075 kp·kg^{-1}	663.8 ± 89.3	10.7 ± 1.3	470.6 ± 75.1	7.6 ± 0.9	-	-	-	-

Table 2.5 presents $\dot{V}O_{2max}$ test scores for international standard Taekwondo athletes, with ranges between 44.0-63.2 *ml·kg·min*$^{-1}$ and 41.6-51.1 ml·kg·min^{-1} for males and females, respectively. Again, these scores contrast positively with those from both other striking (Chaabene et al., 2012; Chaabene et al., 2015) and grappling (Chaabene et al., 2012; Franchini et al., 2011) based combat sports and categorise the Taekwondo athletes from across these studies within the average to high normative ranges for both sexes (Astrand, 1960).

Table 2.5: *$\dot{V}O_{2max}$ test scores for international standard male and female Taekwondo athletes (data are presented as mean ± SD).*

		MALE	FEMALE
Reference	**Test Method**	**$\dot{V}O_{2max}$ (ml·kg⁻min⁻¹)**	
Taaffe & Pieter, 1990	Treadmill	55.8 ± 3.9	46.9 ± 7.5
Rivera et al., 1998	Treadmill	59.3 ± 4.5	48.9 ± 8.0
Markovic et al., 2005	Treadmill	-	49.6 ± 3.3
Bouhlel et al., 2006	Shuttle Run Test	56.2 ± 2.6	-
Butios & Tasika, 2007	Shuttle Run Test	53.7 ± 4.0	-
Markovic et al., 2008	Treadmill	-	49.8 ± 2.8
Perandini et al., 2010	Shuttle Run Test	51.9 ± 2.9	41.6 ± 2.4
Chiodo et al., 2011	Treadmill	63.2 ± 6.1	51.1 ± 2.3
Cubrilo et al., 2011	Treadmill	44.0 ± 3.0	-
Rocha et al., 2016	Shuttle Run Test	52.2 ± 6.5	-
Hausen et al., 2018	Treadmill	49.9 ± 3.6	-
		COMBINED SEX	
Ball et al., 2011	Shuttle Run Test	53.3 ± 5.7	
Chen et al., 2017	Shuttle Run Test	46.2 ± 4.7	

Whilst all of the aforementioned literature gives an insight into the physical and physiological profile of international standard Taekwondo athletes, as with body composition and given the mixed general and specific methods utilised to examine these factors, it is hard to gain an accurate perspective. Despite this, these results would suggest that this demographic have limited maximal dynamic strength, average levels of muscular power and aerobic conditioning, yet high levels of anaerobic conditioning.

2.4. Perceptual/Physiological Demands of Taekwondo Training and Competition

2.4.1. Activity Profiles of Training and Competition

To date no study has examined the activity profiles of Taekwondo training sessions, yet there are many reports in the literature where training session details are provided. However, given the disparity in the design of these sessions it would be difficult to make comparisons. A repeated measures study investigating the activity profiles of athletes conducting parallel training sessions, within a similar preparation period, could potentially elucidate some data to further examine this factor.

A review by Avakian et al. (2016), highlighted that the introduction of new rule changes and PSS technology (see section 2.1), has substantially changed both the activity profiles and gameplay of bouts across age divisions. Examining studies conducted prior to the introduction of PSS in 2008, activity profiles are categorised by activity:recovery ratios ranging from 1:6/7 with the rear leg *dollyo chagi* being the most commonly utilised technique, predominantly delivered in counter play actions to the trunk (Bridge et al., 2011; Bridge et al., 2013; Kazemi et al., 2014; Kazemi et al., 2010; Kazemi et al., 2006; Matsushigue et al., 2009; Santos et al., 2011). Unsurprisingly, post 2008, the activity profile ranges from 1:3/5 with the most common technique still the dollyo chagi (Falco et al., 2014; Falco et al., 2012; López-López et al., 2015; Tornello et al., 2013). However, this technique is now more commonly utilised with the front leg and with a greater proportion of the gameplay to the head, given the higher allocation of point scoring techniques to this area (Jae-Ok & Voaklander, 2016; Kazemi et al., 2014). To date, no study has examined the activity profiles between sexes or of official competition bouts inclusive of current rule changes, which again may have substantially changed both activity:recovery ratios and technical/tactical gameplay patterns.

2.4.2. Perceptual and Physiological Responses of Training

There are a limited number of studies which have examined the ratings of perceived exertion (RPE) and HR responses of differing types of Taekwondo training activities. To date, no study has examined blood based markers of physiological strain inclusive of lactate (BLac) during training sessions. The data within these studies has been presented in a number of differing iterations, including the use of both 6-20 (Borg, 1970) and 10 point ratio (Borg, 1998) RPE scales, concomitant with gross calculations of session-RPE (s-RPE), training impulse and HR variability calculations. This section of the literature review will focus solely on those investigations which have examined complete measurements of RPE, HR and/or $\%HR_{max}$, and can be further assessed for between study comparison. Toskovic et al. (2002) examined the perceptual and physiological effects of a standardised 20 minute Taekwondo session between practitioners of differing standards, where measures of HR and RPE were collected in each 5 minute period. In the advanced groups (n = 7), mean HR responses for the whole session were recorded as 170 ± 15 and 168 ± 10 $beats \cdot min^{-1}$, which represented 89.9 ± 5.8 and 88.3 ± 5.1% HR_{max} in males and females, respectively. Bridge et al. (2007) also assessed the HR responses of varying training activities within typical training sessions lasting between 90-120 minutes in 8 male international standard athletes, where HR responses varied between 128 ± 13 to 161 ± 15 $\text{beats} \cdot \text{min}^{-1}$ representing 65 ± 6 to 81 ± 7% HR_{max}. The RPE responses in the Toskovic et al. (2002) study implemented the 6-20 scale, where mean responses in males were 13 ± 1 (somewhat hard) and in females 12 ± 1 (fairly light – somewhat hard). In comparison, a study by Haddad et al. (2014) examined RPE responses in 12-18 year old males across 368 sessions lasting 74 ± 20 minutes, whilst utilising the 10 point ratio scale and found mean responses per session of 4 ± 1 (somewhat hard).

2.4.3. Perceptual and Physiological Responses of Competition

As highlighted in section 1.1, Taekwondo bouts are 3 x 2 minute rounds in duration, interspersed with a 1 minute recovery and athletes can have up to 7 bouts in a competition day (Butios & Tasika, 2007). To date, only five studies have highlighted the perceptual and physiological challenges associated with international standard Taekwondo bouts, demonstrating a high demand on both the aerobic and anaerobic energetic pathways (see Table 2.6.). As such, the cardiometabolic physiology in competitive bouts is elevated with BLac exhibited at mean values of 7.0-12.2 $mmol \cdot L^{-1}$ at the cessation of a contest despite sub maximal HR (175 – 193 beats·min^{-1}) and RPE (11 fairly light – 14 somewhat hard) values across rounds (Bridge et al., 2014). However, all of these studies were conducted prior to 2008 and the introduction of PSS, making these investigations ecologically invalid on the basis of the altered activity profiles highlighted in section 2.4.1.

Over the past decade there have been a number of studies investigating the perceptual and physiological responses of simulated Taekwondo bouts, which follow the same time structure of official competitive bouts and can be classified as either opponent or pad based (see Table 2.6). To date, only one pad based simulation study has been conducted by Bridge et al. (2013), which was implemented in a controlled area and regulated via an audio signal, yet co-ordinated with the same activity profile of pre 2008 official competitive bouts. HR across rounds and concluding BLac values at the end of the simulation were shown to be markedly lower compared to official competitive bouts, despite near identical RPE values. Specifically in Taekwondo athletes, this study was the first to characterise that the differences in these BLac responses, were a result of five fold increases in both plasma adrenaline and noradrenaline during official competitive bouts. This is manifested by a greater activation of both the sympathetic nervous system and adrenal medulla, invoking an enhanced ‘fight-or-flight’ stress response via increases in both catecholamine and cortisol hormones. Therefore, this demonstrates that pad based simulated bouts are an ecologically ineffective means of recreating the physiological strain of competition.

Table 2.6: *Perceptual and physiological responses during official competitive and simulated Taekwondo bouts in male and female Taekwondo athletes of differing levels (data are presented as mean ± SD Grey area denotes events post PSS and significant rule changes).*

	RPE (a.u.)			**HR (beat·min^{-1})**			**BLac (mmol·L^{-1})**	
TIMEPOINT	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**PRE**	**POST**
OFFICIAL COMPETITIVE BOUTS								
Markovic et al., 2008♀	11 ± 0	12 ± 1	14 ± 1	182 ± 5	190 ± 3	193 ± 3	0.9 ± 0.2	11.7 ± 1.8
Bridge et al., 2009♂	11 ± 2	13 ± 2	14 ± 2	175 ± 15	183 ± 12	187 ± 8	2.7 ± 0.6	11.9 ± 2.1
Matsushigue et al.,2009♂	-	-	-	-	-	183 ± 9	3.1 ± 2.7	7.5 ± 3.8
Chiodo et al. 2011♀♂	-	-	-	175 ± 10	175 ± 10	178 ± 9	2.2 ± 0.5	7.0 ± 2.6
Bridge et al., 2013♂	11 ± 2	12 ± 2	14 ± 3	185 ± 7	189 ± 8	190 ± 9	2.6 ± 0.9	12.2 ± 4.6
PAD BASED SIMULATED BOUTS								
Bridge et al. 2013♂	11 ± 2	12 ± 2	13 ± 3	166 ± 3	174 ± 4	176 ± 2	1.2 ± 0.7	3.6 ± 2.7
OPPONENT SIMULATED BOUTS								
Bouhlel et al., 2006♂						197 ± 2	1.6 ± 0.2	10.2 ± 1.2
Bridge et al., 2018♂	13 ± 1 – 14 ± 2**x**			192 ± 8 – 194 ± 8**¥**			1.9 ± 0.8 – 3.1 ± 1.2**¥**	10.5 ± 3.2 – 13.9 ± 4.2**¥**
Campos et al., 2012♂	-	-	-	156 ± 9	169 ± 9	175 ± 10	-	7.0 ± 1.5
Lopes-Silva et al., 2015♂	11.5 ± 0.3+			167 ± 13	173 ± 10	177 ± 10	**G**	**G**
Hausen et al., 2017♂	-	-	-	173 ± 1	179 ± 11	179 ± 19	-	12.3 ± 2.9
Lopes-Silva et al., 2018♂	**G**	**G**	**G**	164 ± 17	177 ± 13	183 ± 12	**G**	**G**
Yang et al., 2018♂	-	-	-	182 ± 8	183 ± 7	179 ± 8	-	5.6 ± 4.2

♂ - Male participants; ♀ - Female participants; ♀♂ - Mixed participants; **G –** Data only shown in graph format;

+ Average across rounds; **x** Average per bout across 4 contests

Opponent based simulations utilise the same rules and regulations as described in section 2.1 versus another competitor. Investigations employing opponent based simulations show a large disparity across results, highlighting them as both effective and also ineffective at replicating the cardiometabolic demands of official competitive bouts. However, this could be postulated as being attributed to a number of confounding variables. For example, studies by Campos et al. (2012), Lopes-Silva et al. (2015) and Yang et al. (2018) were all conducted without the use of a body protector, given participants were equipped with a portable indirect calorimetry unit allowing only limited contact. Studies by Hausen et al. (2017) and Lopes-Silva et al. (2018), both utilised a novel method of embedding an indirect calorimetry unit into a padded bag, which was worn on the participants back and the unit mouth piece embedded into the protective headgear. Whilst this allowed an increase in contact during these bouts, this also results in additional mass carriage of the equipment, which is considerably heavier than the standard attire worn in official competitive bouts. Additionally, none of these studies utilised PSS systems, which were omitted due to negatively effecting the indirect calorimetry measurement and were conducted within a number of settings, including laboratories, further reducing ecological validity.

Both the studies by Bouhlel et al. (2006) and Bridge et al. (2018) were conducted with non PSS full protective equipment, in an ecologically valid setting including referees, which may also explain why the perceptual and physiological results of these studies are markedly similar to those of official competitive bouts pre 2008. All of the aforementioned studies have also been conducted across a number of differing iterations of the official competition rules and exhibit a variance in activity profiles (ranging from 1:2-1:8). This makes both within opponent based simulation and between official competition based comparisons inexpedient. Irrespective of divergences in the research, all of the studies in both section 2.4.2 and Table 2.6. highlight there is a clear cardiometabolic demand placed upon Taekwondo athletes during both training and competition. Further research is required to elucidate more data during Taekwondo training and also in official competitive contests, utilising the most current rules and regulations given the aforementioned changes in both activity profiles and gameplay.

The previous sections have served to highlight the sport of Taekwondo, its rules and regulations, the anthropometric/physical profile of its athletes and the demands of training/competition. It is apparent that international standard Taekwondo athletes are required to be in peak condition in order to compete within a sport that requires a prominent level of technical and tactical expertise, physical qualities and places a high demand on a number of perceptual and physiological systems. However, a key aspect of the sport which has not been discussed in depth thus far is weight categorisation, were it is compulsory for athletes to ‘weigh in’ and compete against opponents of equal BM. As with all weight categorised sports, Taekwondo athletes engage in practices to reduce BM, with this growing into an inherent cultural paradigm. Few of the studies in the previous sections have addressed this issue in their designs and the subsequent sections will now serve to explore this in greater detail, which is the central theme of this thesis.

2.5. History of Weight Categorisation in Sport

Historically from as long ago as the ancient Olympic Games, weight categorisation was not a consideration of any sporting event, including the combat sports of Wrestling and *Pankration,* which had no upper or lower BM limits. The concept originated in the sport of boxing during the early 18th century, when in 1738 a prize fighter named Jack Broughton was the first to promote the use of 2 separate weight categories, classified into lightweight and heavyweight, both above and below 160 pounds (72.7 kg or 11 stone 4 pounds). From this original ideology many sports have adopted weight categories or limits, to classify competitors of equal proportion for respective events as shown in Table 2.7.

The evolution of weight categorisation in Taekwondo has a uniquely different timeline to many of the other combat sports but does, however, follow a similar trend to Wrestling. Taekwondo competitions were originally contested with no weight category limits until the 1st World Championships held in 1973, when two weight categories were introduced both above and below 64 kg. In the next edition of the 2nd World Championships this had been expanded to eight categories and by the 4th World Championships edition in 1979, further expanded to ten categories. At the 7th World Championships in 1985, the weight categories were reduced once again to eight and in the following 8th World Championship edition in 1987, a further eight categories for female competitors were also introduced. The established weight category limits remained the same across both sexes until the 14th 1999 World Championships, when they were all increased, which was also repeated in the 19th 2009 World Championships for both male and female divisions (World Taekwondo, 2018b). As previously highlighted in section 2.1 Taekwondo was introduced into the Olympic programme at the Sydney 2000 Olympic Games and unlike every other weight regulated sporting event, was given a reduced quota of categories (four for males and females) (see Table 2.1). These categories are not used in any other format of Taekwondo competition and are amongst the largest differences (>10 kg) of any weight categorised sport contested globally.

Table 2.7. *Classifications of various weight categorised sports*

Professional Boxing		**Amateur Boxing**		**Judo**		**Taekwondo**		**Wrestling (Freestyle)**		**Wrestling (Greco-Roman)**	**Karate**		**Weightlifting**		**Mixed Martial Arts (MMA)**	**Professional Horseracing (UK)**
MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	MALE	FEMALE	MALE	FEMALE	M & F	M & F
- 47.6 kg	- 46.3 kg	**46-49 kg**	45-48 kg	**- 60 kg**	**- 48 kg**	-54 kg	-46 kg	**- 57 kg**	**- 50 kg**	- 55 kg	**- 60 kg**	**- 50 kg**	**- 56 kg**	**- 48 kg**	- 52.2 kg	Flat racing - 50.8 kg to 63.5 kg
- 48.9 kg	- 47.6 kg	**- 52 kg**	- 51 kg	**- 66 kg**	**- 52 kg**	**-58 kg**	**-49 kg**	- 61 kg	**- 53 kg**	**- 60 kg**	**- 67 kg**	**- 55 kg**	**- 62 kg**	**- 53 kg**	- 56.7 kg	
- 50.8 kg	- 48.9 kg	**- 56 kg**	- 54 kg	**- 73 kg**	**- 57 kg**	-63 kg	-53 kg	**- 65 kg**	- 55 kg	- 63 kg	**- 75 kg**	**- 61 kg**	**- 69 kg**	**- 58 kg**	- 61.2 kg	
- 52.2 kg	- 50.8 kg	**- 60 kg**	- 57 kg	**- 81 kg**	**- 63 kg**	**-68 kg**	**-57 kg**	- 70 kg	**- 57 kg**	**- 67 kg**	**- 84 kg**	**- 68 kg**	**- 77 kg**	**- 63 kg**	- 65.8 kg	
- 53.5 kg	- 52.2 kg	**- 64 kg**	- 60 kg	**- 90 kg**	**- 70 kg**	-74 kg	-62 kg	**- 74 kg**	- 59 kg	- 72 kg	**+ 84 kg**	**+ 68 kg**	**- 85 kg**	**- 69 kg**	- 70.3 kg	Jump racing - 63.5 kg to 76.0 kg
- 55.2 kg	- 53.5 kg	**- 69 kg**	- 64 kg	**- 100 kg**	**- 78 kg**	**-80 kg**	**-67 kg**	- 79 kg	**- 62 kg**	**- 77 kg**			**- 94 kg**	**- 75 kg**	- 74.8 kg	
- 57.2 kg	- 55.3 kg	**- 75 kg**	- 69 kg	**+ 100 kg**	**+ 78 kg**	-87 kg	-73 kg	**- 86 kg**	- 65 kg	- 82 kg			**- 105 kg**	- 90 kg	- 77.1 kg	
- 58.9 kg	- 57.2 kg	**- 81 kg**	- 75 kg			+87 kg	+73 kg	- 92 kg	**- 68 kg**	**- 87 kg**			**+ 105 kg**	+ 90 kg	- 79.4 kg	
- 61.2 kg	- 58.8 kg	**- 91 kg**	- 81 kg					**- 97 kg**	- 72 kg	**- 97 kg**					- 83.9 kg	
- 63.5 kg	- 61.2 kg	**+ 91 kg**	+ 81 kg			**+ 80 kg**	**+ 67 kg**	**- 125 kg**	**- 76 kg**	**- 130 kg**				**+ 75 kg**	- 88.5 kg	
- 66.7 kg	- 63.5 kg														- 93.0 kg	
- 69.9 kg	- 66.7 kg		**48-51 kg**												- 102.1 kg	
- 72.6 kg	- 69.9 kg		**57-60 kg**												- 120.2 kg	
- 76.2 kg	- 72.6 kg		**69-75 kg**												+120.2 kg	
- 79.4 kg	- 76.2 kg															
- 90.9 kg	- 79.4 kg															
+ 90.9 kg	+ 79.4 kg															

Weight categories highlighted in bold are those included in the Olympic Games.
All weight category information has been pertained from the relevant world governing body

2.6. Making Weight in Combat Sport

The rationale for weight categorisation is to promote fairer contests between competitors of equal proportion (Langan-Evans et al., 2011). Despite this, it has been suggested that many weight categorised athletes lose large amounts of BM in order to gain competitive advantages in either stature, limb length or power to mass ratio. Concomitantly with the development of weight categorisation in sports, losing BM to compete within a specified category known as *making weight* (also referred to as *cutting*), has equally evolved to become an integral part of each sports respective culture. Making weight can occur in both acute (termed 'acute or rapid weight loss' – A/RWL) and chronic timeframes and has grown in frequency, magnitude and occurrence over a number of decades, to where there has been a global call to ban these practices (Artioli et al., 2016). The research highlighted in this section will focus specifically on the making weight practices of both professional and amateur combat sports, in both *grappling* and *striking* disciplines, before concluding with those examinations conducted specifically within Taekwondo.

2.6.1. Grappling: Judo

Judo is governed by the International Judo Federation (IJF), where *judoka* are required to weigh in no later than 8.00pm on the day prior to a competition. Since 2014 the IJF have also instigated a random weigh in, which takes place one hour prior to the start of competition, where athletes are notified by a list placed next to the warm-up area. There have been a number of making weight related incidents reported in Judo over successive years, most notably the failed weigh in of British Olympic judoka Debbie Allan as a results of scale tampering (Soames, 2000) and also the death of Korean Olympic judoka Chung Se Hoon (AP News, 1996). To date a number of studies have examined the making weight practices of judoka and to conduct investigations with a valid and reliable measurement tool, Artioli et al. (2010d) developed a *rapid weight loss* questionnaire (RWLQ), which examines a number of factors to generate a RWLQ score (RWLS). The RWLQ has subsequently been utilised in a number of studies (Artioli et al., 2010b; Barley et al., 2017; Brito et al., 2012; Reale et al., 2018a), highlighting a high frequency

(68.2-89%) and magnitude (2.5-8.5%) of BM loss in an adult judoka population. The most common methods employed to achieve these BM losses, are energetic restriction (gradual dieting; skipping meals; fasting), increased energetic expenditure plus active (training with sauna/sweat suits; heated training environment) and passive (restricting fluids; spitting; saunas) dehydration techniques. Interestingly, all of these studies found differences in RWLS and/or behaviours between competitive levels, with international standard judoka engaging in more extreme practices, yet no differences between sexes and athletes in differing weight categories.

Escobar-Molina et al. (2015) examined the differences between judoka of different age divisions, where the magnitude of BM loss was greater in Senior (>20 years) compared to Junior (17-20 years) and Cadet (<17 years) athletes. However despite this, an investigation by Berkovich et al. (2016), highlighted that in a group of adolescent judoka (12-17 years), the frequency of making weight practices was still markedly high (80%) with the magnitude of BM loss ranging from 2.5-7.8%. Interestingly, the methods and influences of these practices were similar to adult judoka, however, it was highlighted that parents were also a main influencer for the engagement of making weight practices in this age demographic. Independent of age division, sex or competitive level the typical occurrence of these practices is 3-5 times annually, with BM losses targeted over a period of 7-14 days.

The random re-weigh in ruling limiting BM to below 5% of a respective weight category, was introduced by the IJF in an attempt to reduce the making weight practices of judoka. A study by Malliaropoulos et al. (2017) investigating BM loss practices in a group of male and female Senior British judoka, has demonstrated that the same frequency (84%), magnitudes (3%) and occurrences (5) are comparable to research conducted in Judo athletes prior to 2014, when the rule was introduced. This study demonstrates the potential inefficacy of this regulation, albeit in a limited (n = 255) cohort with singular nationality and the need for a weight category management programme, which has been proposed previously (Artioli et al., 2010a).

2.6.2. Grappling: Wrestling

Wrestling is divided into two distinct disciplines of Freestyle and Greco-Roman and is governed by United World Wrestling (UWW). Both disciplines have differing weight category limits for both males (Freestyle/Greco-Roman) and females (Freestyle only), respectively. UWW currently follow a two day competition format, whereby semi-finals and finals are conducted on the second day. Weigh ins are held the day before each competition round, with the second day weigh in granting a 2 kg allowance above the allotted weight category, where all wrestlers must wear their competition singlet (As of January 2019 this allowance will be removed). The making weight practices of wrestlers, particularly in the US collegiate system, are the most researched of any combat sport with reviews/studies dating as far back as the early 1930s (Kenney, 1930) and mid 1940s (Doscher, 1944). From November to December of 1997, three US collegiate wrestling athletes, attending universities in three differing locations, died from hyperthermia and/or rhabdomyolysis attributed to extreme hypohydration (Centers for Disease Control and Prevention, 1998). Since these events, there has been a raft of research examining the making weight practices of both high school and collegiate wrestlers including a number of positions stands (ACSM, 1976; Oppliger et al., 1996) and regulation papers (Oppliger et al., 1998; Oppliger et al., 2006).

Since US high school and collegiate wrestlers follow different rulings to those set out by UWW (including 14 to 10 categories per sex; day of competition weigh ins <4 hours prior to contests; minimum weekly BM loss allowance of 1.5%; minimum BF% of 5-7% in males and 12% in females; urine specific gravity (U_{sg}) <1.020) the remainder of this section will focus on studies examining making weight practices in UWW wrestling disciplines only. Utilising both the RWLQ and other methods, various studies (Alderman et al., 2004; Barley et al., 2017; Kordi et al., 2011; Reale et al., 2018a) have demonstrated a wide frequency (53-97%) and magnitude (4.8-5.9%) of BM loss, in a multitude of wrestling populations. The most common methods employed to attain these losses are generally A/RWL procedures including active (training with sauna/sweat suits; heated training environment) and passive (restricting fluids; spitting; saunas) dehydration techniques, employed in acute timeframes (7-10 days) and conducted around 5 times annually.

There is limited research examining both the differences in BM loss between wrestlers of differing sexes and age divisions. Reale et al. (2018a) found no differences in RWLS between sexes, yet similarly to Judo, differences between competitive levels in their study of Australian international standard combat sport athletes. Alderman et al. (2004) examined the differences in rapid weight gain (RWG) between Cadet (15-16 years) and Junior (17-18 years) wrestling athletes and found a greater magnitude of BM loss in the older age group (albeit only by 0.68 kg) and a specific investigation by Viveiros et al. (2015) examining 11-15 year old wrestlers, highlighted homogeneous frequency, magnitude and occurrence of BM loss to those in adult cohorts.

2.6.3. Grappling and Striking: Mixed Martial Arts (MMA)

MMA can be defined into both amateur and professional codes. Professional MMA contests are governed by a number of world sanctioning bodies (also known as promotions) including Bellator, Absolute Fighting Championship Berkut, Cage Warriors, with undoubtedly the largest global promotion being the Ultimate Fighting Championship (UFC). Typically these sanctioning bodies conduct weigh ins >24 hours prior to a contest and where an MMA athlete fails to meet their weight category limit, it can be agreed that a bout may proceed but at *catch weight*, with the failing athlete forfeiting a percentage of their *purse* to the opponent. In the case of championship bouts, a failed weigh in results in the cancellation of the bout (or a replacement fighter), as these type of contests can only be validated if both competitors meet the weight category limit. In the instance of competing at catch weight due to a weigh in failure, the opponent can stipulate they also re-weigh in and do not exceed a set weight limit in the hours preceding the contest (Prentice, 2018). Regardless of these regulations, MMA has gained a reputation amongst combat sports for having some of the most extreme making weight practices, which have resulted in a number of deaths over many years (Crighton et al., 2016; Fernandez, 2015; Murugappan et al., 2018). A limited number of studies (Barley et al., 2017; Coswig et al., 2015; Crighton et al., 2016; Jetton et al., 2013; Matthews & Nicholas, 2017), have highlighted an unprecedented frequency (95-100%) and magnitude (4.4-11%) of BM loss in only the days and hours preceding contests. Whilst the occurrence of these losses are less than other combat sports, a case study conducted on a world champion professional MMA competitor (Kasper et al., 2018), elucidated an even greater magnitude of BM loss (18.1%) across an 8 week 'phased' preparation period. MMA athletes engage in a series of both chronic (energetic restriction/increased expenditure) and acute (passive/active dehydration) methods, encompassing a range of techniques. Unsurprisingly, these athletes also employ a number of unconventional methods of BM loss, including *water loading*, the application of topical alcohol/gels to increase sweat production and hot towel wrapping (Barley et al., 2017; Crighton et al., 2016; Kasper et al., 2018). There are currently no data examining the differences between sexes, competitive levels or age divisions and investigations conducting this research is urgently needed, given the extreme and dangerous making weight practices that are commonplace within the sport.

2.6.4. Striking: Boxing (Professional)

Professional boxing is governed by four main world sanctioning bodies: the International Boxing Federation (IBF), World Boxing Association (WBA), World Boxing Organisation (WBO) and the World Boxing Council (WBC) with the latter being regarded as the most prestigious promotional body. Typically, these sanctioning bodies will weigh in boxers not more than 30 hours and no less than 24 hours prior to a bout. The WBC stipulates that boxers must be weighed both 30 days and 7 days before a bout and not exceed more than 10% and 5% of BM mass at these time points, respectively (FightNetwork, 2014). In the instance a boxer fails to meet their weight category limit, the regulations are similar to the aforementioned rulings in professional MMA contests i.e. catch weight, forfeit of purse etc. Research into the making weight practices of professional boxers is extremely limited, yet there have been a number of media pieces highlighting the dangers (Collins, 2014), with professional boxer Danny O'Connor suffering renal failure in his bid to make weight for a world title fight (BBCSport, 2018). A case study report by Morton et al. (2010), characterised the previous BM loss practices of a professional boxer, which included chronic energetic restriction (inclusive of total caloric and fluid restriction 48 hours prior to weigh-in) and extreme dehydration methods, including exercise in a sauna/sweat suit resulting in a BM reduction of over 13%. Daniele et al. (2016) also investigated RWG observed in professional boxers post weigh in and despite not finding significance between this factor and boxing performance, the study noted some alarmingly high incidences of BM gain by up to 9.3% in a limited time period. There is certainly scope for a plethora of research studies further examining making weight practices in this demographic.

2.6.5. Striking: Boxing (Amateur)

Amateur boxing is governed by the International Boxing Association (AIBA – originally the Association Internationale de Boxe Amateur) and conversely to professional boxing, athletes are required to weigh in under two regulations: the general and daily weigh in. At the beginning of a competition all boxers are expected to attend a general weigh in, which is held no less than 6 hours prior to the start of the first contest. Boxers who are successful in competing in subsequent rounds must then attend the daily weigh in, which is held no longer than 3 hours before the start of the first contest. There have been a number of making weight related incidents reported in amateur boxing, most notably in the cases of boxers Frankie Gavin and Gary Russell Jr during the 2008 Beijing Olympics (Rowbottom, 2008; Shpigel, 2008) and the death of an amateur boxer in 2018 due to diuretic use (WATE.com, 2018). Again and similarly to professional boxing, there is a paucity of research examining the making weight practices of this demographic, with only three studies being conducted to date. Hall and Lane (2001) co-ordinated structured interviews with amateur boxers (n = 16) who described a mean of 8% BM loss across a competitive season in order to reach ‘championship weight’. Studies by both Reale et al. (2018a) and Barley et al. (2017) (utilising a modified RWLQ), highlighted that the frequency of BM loss in amateur boxers ranged from 93-95%, with magnitudes of 3.6-6.8% typically occurring 4-6 times annually across a period of 12-26 days. Yet again and similarly to other studies, there are no differences between sexes. Typically these athletes will engage in methods of chronic energetic restriction and increased energetic expenditure, whilst utilising acute active (skipping/running in sweat/sauna suit) and passive (restricting fluids) dehydration techniques to achieve their prescribed weight category and again further research in this cohort certainly warranted.

2.6.6. Striking: Taekwondo

Historically, Taekwondo athletes were expected to weigh in on the morning of competition, yet since 2001 they now do so on the day prior. Similarly to Judo, in June 2018 WT introduced a rule change, whereby a number of randomly selected competitors in each respective weight category, are required to re-weigh in on the morning of competition and must be within 5% BM of their category or risk disqualification (World Taekwondo, 2018a). There have been a number of deaths associated with making weight practices in Taekwondo, which have occurred both before and after the introduction of the new ruling (Forsyth, 2018; MasTKD, 2018). Utilising the RWLQ and other survey tools, there have been a various studies conducted examining the practises in Taekwondo athletes of differing ages and competitive levels. Collectively, these studies have demonstrated that regardless of sex, in Senior (>18 years) athletes the frequency of making weight practices is 63-91%, with BM loss magnitudes ranging between 3.6-6.1% in order to compete (Barley et al., 2017; Brito et al., 2012; da Silva Santos et al., 2016; Fleming & Costarelli, 2009; Reale et al., 2018a). The occurrence of these losses is based on the annual amount of competitions an athlete may attend, typically between 4-9 times per year and across a 10-28 day period. Similarly to Senior athletes, in Juniors (14-17 years) the frequency is exhibited at 76-91%, whereas there is a reduction in the magnitude of BM losses (1.8-4.9%) with reduced occurrences (3) and timescales (3-7 days) (Diniz et al., 2014; Janiszewska & Przybyłowicz, 2015; Kazemi et al., 2011). These levels of BM losses are accomplished in both acute and chronic timeframes, via energetic restriction and increased expenditure, concomitant with both active (use of sweat/sauna suits) and passive (restricted fluid intake) dehydration techniques (Fleming & Costarelli, 2007). The utilisation of A/RWL techniques and dehydration via heated environments (in particular the use of saunas and hot baths) as a means to reduce BM appears to be lower amongst the other combat sports, yet similar to other striking disciplines such as boxing.

2.6.7. Grappling and Striking Combat Sports Comparisons

With the competitive objectives of both grappling and striking combat sports being uniquely different, it is unsurprising that there are disparities in the approaches to making weight practices amongst the athletes of these disciplines. Interestingly, it appears that grappling based combat sports (Wrestling/Judo/MMA) favour losing large amounts of BM in acute timeframes by a means of A/RWL methods. Striking combat sports (Boxing/Taekwondo) may lose BM over more protracted periods with a preference for decreased energetic intake (EI) and increased exercise energy expenditure (EEE), with these gradual approaches limiting the amount of A/RWL required to make a specified weight category. For striking this may be logical, given overall whole BM hinders propulsion, whereas in grappling there is a requirement for greater momentum and power to mass ratio. To test this hypothesis two studies (Reale et al., 2016, 2017a) examined the differences between RWG in judoka/boxers and found successful competition outcomes were linked to this factor in Judo, however not in Boxing, which was also confirmed in an another investigation by Zubac et al. (2018). Therefore the data demonstrating the preferred methods of BM loss in Taekwondo athletes concurs favourably with the changing athlete anthropometric profiles highlighted in section 2.2.

2.6.8. Influences on Making Weight

Collectively, the previously aforementioned studies have highlighted that athlete motivations to engage in making weight practices are driven by the desire to gain advantages in physicality over opponents. To date very few investigations have provided evidence to substantiate this assertion directly (Kordi et al., 2011; Pettersson et al., 2013), whereas only a small number have linked this to actual competitive success outcomes (Alderman et al., 2004; Artioli et al., 2010b; Reale et al., 2016; Wroble & Moxley, 1998). Compellingly, it also appears that sex plays no part on the influence to engage in these practices, yet competitive level does. Whilst all of the aforementioned studies provide a sound quantitative basis for the investigation of the influences and motivations for engaging in making weight practices, to date only three qualitative studies have been conducted (by the same research group) to examine these factors in greater detail. Research by Pettersson et al. (2013); Pettersson et al. (2012) in a group of Olympic combat sport athletes (including four Taekwondo athletes) demonstrated that factors related to physique and self-actualisation via mental advantage, were as equally important congruent with the advantages gained in physicality. Furthermore in a qualitative case study design, Pettersson and Pipping Ekström (2014) examined how the transition of a female amateur boxer through both national and international ranks, leading to a coaching career was governed consistently in all phases via changes in identity, balanced perspective and knowledge.

One synonymous commonality between all of the aforementioned studies conducted in both grappling and striking based combat sports, is that coaches, training partners and other competitors, are all highlighted to have the greatest influence on the decision to engage in making weight practices. Furthermore, combat sport athletes below the age of legal responsibility are also heavily influenced by parents. Alarmingly, a disturbing report by Sansone and Sawyer (2005), has described the making weight practices of a 5 year old wrestling athlete who was coerced into losing 10% of BM by his father. Despite both of these groups being identified as key stakeholders in combat sport athlete making weight and nutritional behaviours, very few investigations have evaluated their respective attitudes, beliefs and knowledge surrounding these practices (Sossin et al., 1997; Umoren et al., 2001; Weissinger et al., 1993). Currently there have been no qualitative studies examining the coach and parent perceptions to these practices, or their view on being regarded as a major influence in the process and further investigations are certainly warranted to elucidate additional data around this paradigm in combat sports.

Further to the making weight practices and influences highlighted in this section, it is vital to understand the psychological and physiological effects these methods may elicit. The following sections will serve to examine BM loss techniques employed by Taekwondo athletes across both acute and chronic time periods, inclusive of seminal research in each area emphasising both the potential positive and negative outcomes on both health and performance.

2.7. General Overview of Acute Body Mass Loss Methods and Psychological and Physiological Effects on Health and Performance

The human organism can be divided into various sections, all of which may be manipulated to induce a reduction in BM. Approximately 60% of BM is comprised of water (TBW), which is divided into 65% intracellular (ICW) and 35% extracellular (ECW) components (see Figure 2.2) (Reale et al., 2017b). ICW is the cytosol contained within various cell structures, whereas ECW is divided between interstitial (fluid surrounding cell structures allowing movement between cell membranes), intravascular (both blood plasma/lymph) and transcellular (cerebrospinal, synovial joint, gastrointestinal spaces) compartments (Péronnet et al., 2012). The TBW within these compartments is either 'free' or 'bound' and both can be reduced to elicit A/RWL via a number of processes inclusive of respiration, urination and perspiration (Reale et al., 2017b).

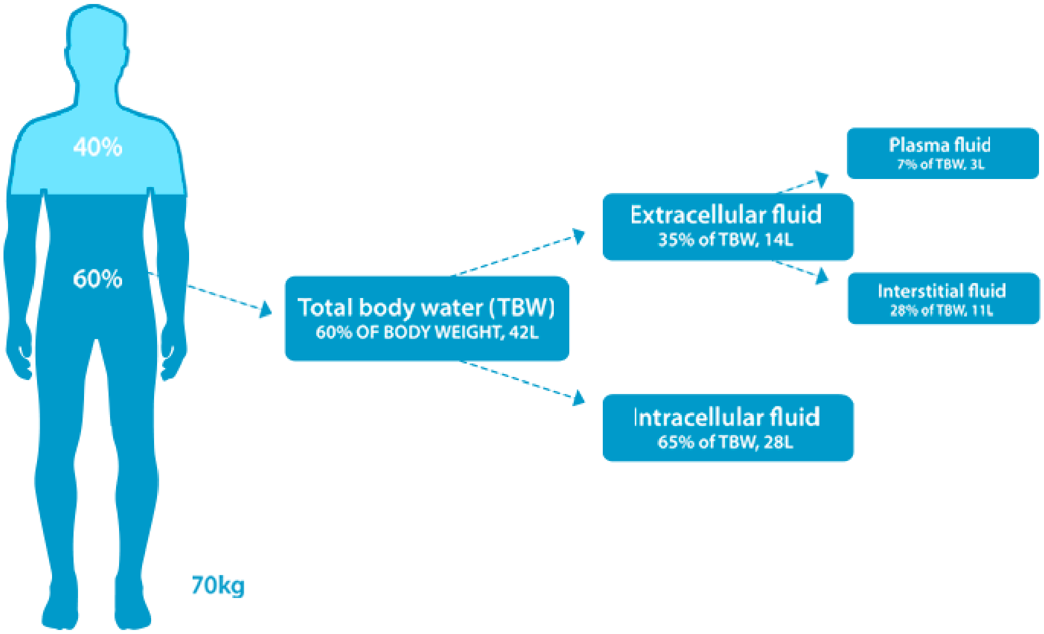


Figure 2.2: *Endogenous TBW compartmental distribution in a 70 kg male*

(Source: Hydration4Health (2018)

Reduction of BM via varying tissues such as LM and FM, can occur in both acute and chronic timeframes, which is dictated by their composition. The chemical composition of LM (skeletal muscle) comprises of approximately 20% protein structures (myosin, actin, tropomyosin, troponin, myoglobin), 5% salts, phosphates, ions, glycogen, intramuscular triglycerides and 75% water (Wang et al., 1999), where free water can be liberated acutely in tandem with bound water i.e. molecules such as glycogen (Tarnopolsky et al., 1996). FM can be subdivided into either essential or non-essential tissues. Essential FM tissues are stored in the organs (brain, heart, liver, kidneys, spleen, lungs and intestines), bone marrow and central nervous system, with non-essential FM tissues also subdivided into both visceral (around the abdominal organs) and subcutaneous (contained under the skin surface) types. Essential FM requirement in males has been established as 6% (Friedl et al., 1994), whereas in females is higher, given the sex specific differences in endocrine related functioning for sexual reproduction. Typically females will carry up to 7% more essential FM, independent of the aforementioned areas including the breasts, pelvis and upper leg regions (Katch et al., 1980). FM is predominantly comprised of adipocytes (containing lipid droplets), fibroblasts, macrophages and only 10% water (Thomas, 1962). Adipocytes are also recognised as an endocrine organ responsible for the production of various hormones, inclusive of leptin and adiponectin (Kershaw & Flier, 2004). Typically reductions in both LM protein structures and FM adipocytes will occur in prolonged chronic timeframes due to protective and endocrine related processes regulated by metabolism (discussed in more detail in section 2.8.2).

Combat sport athletes employ numerous methods to manipulate the various these BM sections (see section 2.6). However, these methods are often utilised without the consideration of either the positive or negative effects they may manifest on both overall health and performance. This section will serve to examine this specifically in Taekwondo athletes, however, where there may be an absence of research conducted in this demographic, the applicable practices of other combat sport disciplines and/or general investigations will also be considered.

2.7.1. Endogenous Total Body Water Balance and Dehydration

Endogenous TBW balance is regulated by both a number of input and output systems, as demonstrated in Figure 2.3. Dehydration can be defined as the loss of endogenous TBW, achieved via active (exercise based) and/or passive (non-exercise based) methods, which can result in both hyper and/or hypohydration. These losses can be characterised as hypertonic (loss of endogenous TBW, which concentrates osmolality), isotonic (concomitant loss of endogenous TBW and osmolality) or hypotonic (reduction in plasma osmolality content which dilutes exogenous TBW) states (Grandjean et al., 2003). These varying dehydrative processes can cause both hyponatremia (an excess of endogenous TBW due to low osmolality <135mmol/L via hyperhydration) and/or hypernatremia (a reduction in endogenous TBW due to high osmolality >145mmol/L via hypohydration) leading to a number of health related issues inclusive of nausea, vomiting, seizures and coma which may lead to death (Fried & Palevsky, 1997).

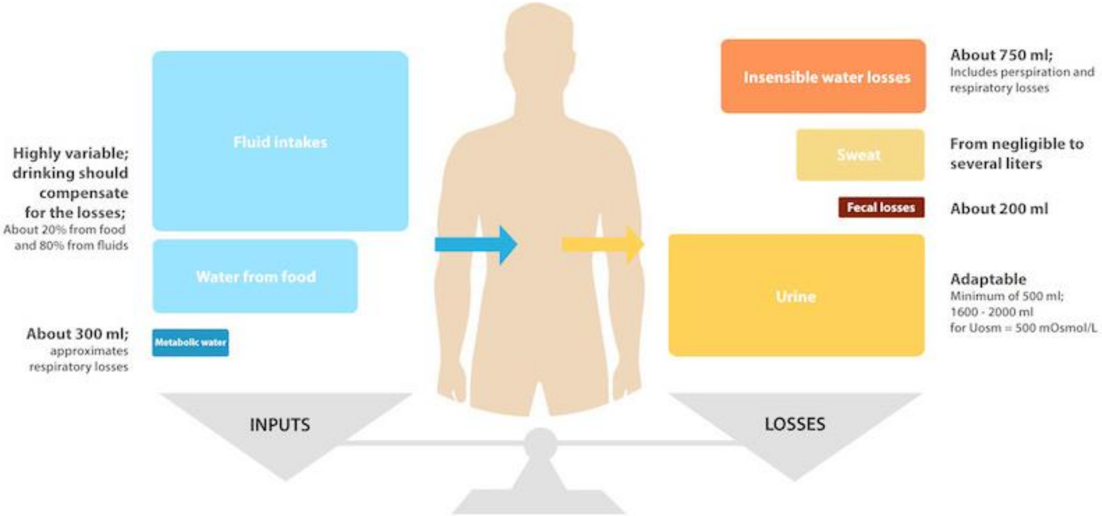


Figure 2.3: *TBW fluid dynamics input and output systems*

(Source: Hydration4Health (2018)

As highlighted in Figure 2.3 the human organism can lose TBW via a number of processes, all of which are orchestrated by a number of physiological systems. The predominant system, the renal feedback loop, regulates plasma sodium osmolality between a limited set point of 135-145 mmol·L^{-1}. This system dictates the loss of endogenous TBW via an inverse relationship, whereby when sodium levels are high, the hypothalamus stimulates the pituitary gland releasing the hormone vasopressin (or anti-diuretic hormone - ADH), which in turn acts on the kidneys to reabsorb free TBW, yet reciprocally at low levels, vasopressin secretion is reduced, causing free TBW to be excreted (see Figure 2.4) (Verbalis, 2003). Combat sport athletes use a variety of techniques to manipulate this physiological system and induce BM loss, which are described in detail in the subsequent sections.

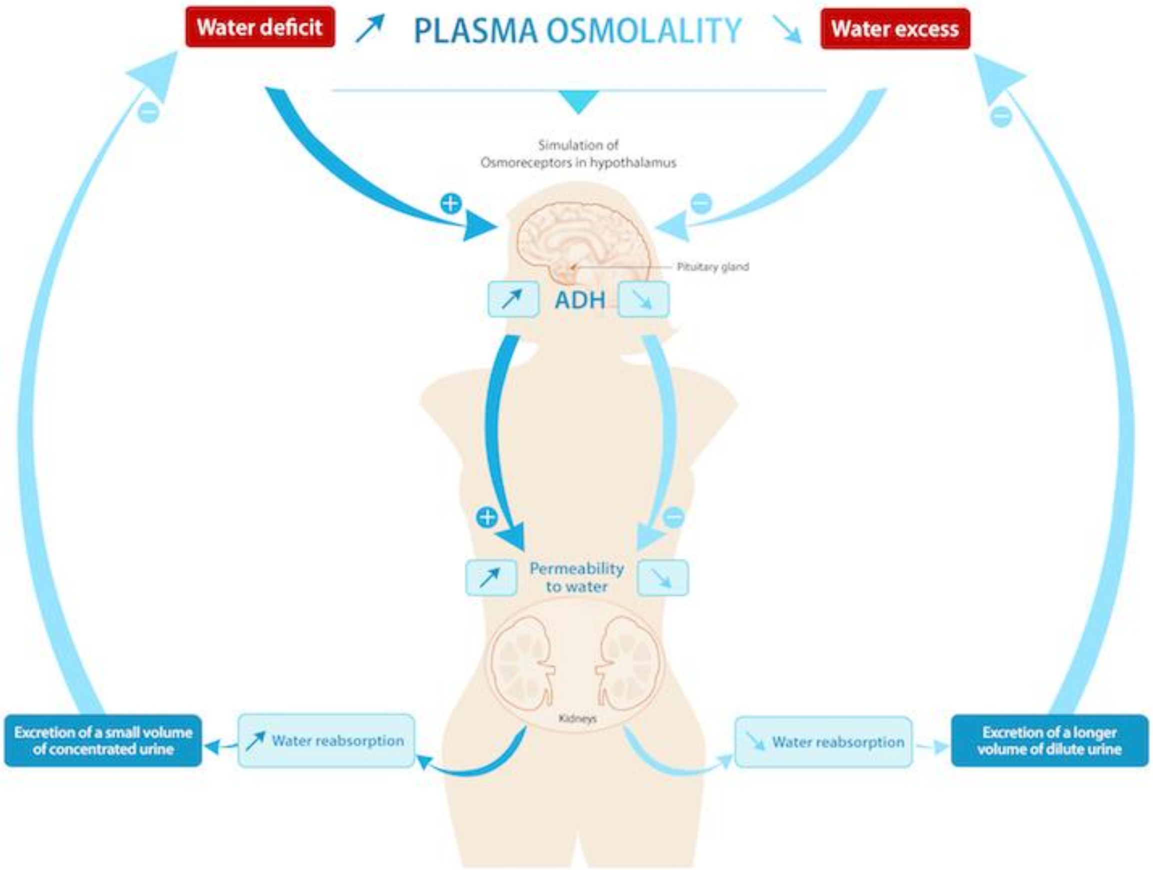


Figure 2.4: *Hypothalamic regulation of plasma osmolality via vasopressin (ADH)*
(Source: Hydration4Health (2018)

2.7.2. Gut Content Manipulation

Few studies have been conducted, demonstrating that a variety of the combat sport disciplines utilise passive methods of gut content manipulation in order to reduce BM in acute timeframes, from 72 hours leading into the final hours preceding a weigh in (Barley et al., 2017; Brito et al., 2012; Reale et al., 2017b). A review by Reale et al. (2017b), elucidates that these methods generally include the employment of both laxatives and vomiting, to reduce stomach and bowel volume content. Further to this, many combat sport athletes will reduce dietary fibre intake, reducing bowel faecal bulk and improving the efficacy of bowel movement transit (Kasper et al., 2018; Reale et al., 2018b). An investigation by Fleming and Costarelli (2007), has highlighted that the Taekwondo athletes within their study, employed a low fibre diet leading into the final five days prior to a competition weigh in. In clinical settings it has been shown that a reduction in total fibre intake of <10g per day can improve bowel transit and is a safe and effective method prior to colonoscopy (Lee et al., 2018; Wu et al., 2011). Whilst more studies are required to examine the efficacy of this practice, this appears to be a stark contrast in comparison to laxatives, which have been demonstrated to reduce exercise capacity and further induce hypertonic hypohydration via hypernatremia when coupled with other dehydration methods (Holte et al., 2004).

2.7.3. Dietary Sodium/Fluid Manipulation and Diuretic Use

As highlighted in section 2.6.3, combat sport athletes in MMA will typically manipulate osmolality passively via water loading and this has been shown as an effective method of BM reduction in a laboratory controlled trial (Reale et al., 2018b). However, there have been limited studies demonstrating that Taekwondo athletes engage in this practice, with other common passive dehydration strategies employed to influence osmolality, inclusive of reductions in dietary sodium/fluid intake and/or use of diuretics (Barley et al., 2017; Reale et al., 2018a).

Fleming and Costarelli (2007), highlighted that the Taekwondo athletes within their study employed a transient reduction in dietary sodium intake, in the period leading up to a competition weigh in. Dietary sodium intake has been highlighted as an important regulator of endogenous TBW balance (Maughan & Leiper, 1995; Stanhewicz & Kenney, 2015) and during combined energy restriction and exercise (James et al., 2015). Typically dietary sodium restriction (<500mg) is employed for the treatment of individuals with chronic kidney injury and/or cardiovascular hypotension (Krikken et al., 2009), with a by-product of this treatment being a reduction in BM via urinary diuresis. Dietary sodium intake has been shown to have a parallel relationship with vasopressin, whereas when intakes are reduced, urinary diuresis is increased, thus inducing a reduction in BM via hypertonic hypohydration (Kjeldsen et al., 1985). This is yet to be studied in an athletic demographic and the research understanding the mechanisms and prescriptions of this process are urgently needed. Despite not being well established in the literature, a reduction in dietary sodium intake may lead to hyponatremia, when excessive diuresis stimulates the renal feedback loop to upregulate vasopressin beyond what the system can control (Hix et al., 2011; Lee et al., 2014; Sahay & Sahay, 2014) and induce hypotonic hyperhydration via a syndrome characterised as ‘crash diet potomania’ (Fox, 2002; Thaler et al., 1998).

Dietary fluid restriction has been characterised as a passive method of BM reduction within numerous combat sports, with an investigation by Pettersson et al. (2012), highlighting that Taekwondo athletes reduce fluid intake up to >48 hours prior to a competition weigh in. Dietary fluid restriction has been shown to elicit significant reductions in BM in as little as 37 hours, coupled with increases in sensations of thirst, headaches and ability to concentrate (Shirreffs et al., 2004). An increase in osmolality inducing hypernatremia, generally accompanies a reduction in dietary fluid intake, manifesting in hypertonic hypohydration. However, this would be isotonic if accompanied by a reduction in dietary sodium and has been mainly highlighted in hospitalised individuals with restricted access to non-solute water sources (Palevsky et al., 1996).

Whilst diuretic use has been highlighted in Taekwondo athletic populations (Papadopoulou et al., 2017), information on prescription and employment is sparse, given their use is illegal in sport. There are a number of differing diuretic types, which have numerous actions including the suppression of vasopressin, excretion of sodium and/or promotion of diuresis (Cadwallader et al., 2010), all of which can cause both hypernatremia (via hypertonic hypohydration) and hyponatremia (via hypotonic hyperhydration) in the same manner as dietary sodium restriction i.e. conflicting up/downregulation of vasopressin in the renal feedback loop system.

2.7.4. Active and Passive Perspiration

Hypothalamic thermoregulation is another additional system, which controls endogenous TBW levels via perspiration, to manipulate core body temperature based on a number of environmental and activity based factors (Jenkinson, 1973). Thermoregulatory homeostasis is governed between 35.6 – 37.8°C and during an elevation outside of these levels, the hypothalamus stimulates both capillary vasodilation and sweat glands perspiration, in order to dissipate heat and reduce core body temperature (see Figure 2.5). Perspiration can be regulated either passively via a heated environment or actively via exercise, leading to sweat rates of up to 2 $L \cdot hr^{-1}$, which is why this method is a common means of reducing endogenous TBW for BM loss amongst combat sports and in particular Taekwondo athletes as described in section 2.6.6 (Reale et al., 2017b). However, unlike renal vasopressin modulation, hypothalamic regulation of core body temperature does not control perspiration based on endogenous TBW balance, so this method often leads to hypertonic hypohydration and hypernatremia. This can be congruent with a condition known as hyperthermia, whereby core temperature increases beyond what thermoregulatory system can regulate i.e. it absorbs more heat than it can dissipate (Pyne et al., 2014). Hyperthermia can also be exacerbated in the instance of perspired sweat being restricted from evaporating i.e. with the use of impermeable clothing, which is also a common technique utilised among Taekwondo athletes (da Silva Santos et al., 2016).

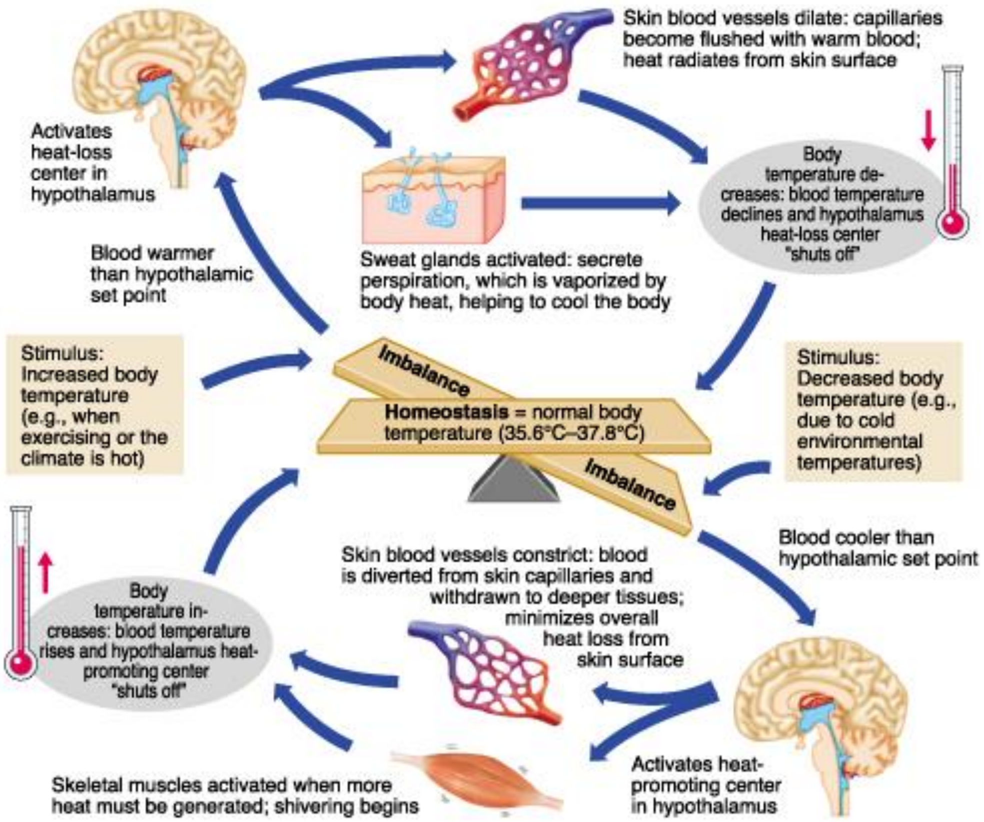


Figure 2.5: *Hypothalamic thermoregulation of core body temperature homeostasis*

(Source: Himme (2018)

Importantly both passive and active perspiration manifest different physiological responses during hypothalamic thermoregulation. Passive perspiration can result in hypovolemia and reduced cardiac stroke volume/output leading to tachycardia and an increase in core temperature (Murray, 1996; Sawka et al., 2015), whereas active perspiration stimulates these responses to a lesser extent (Akerman et al., 2016; Savoie et al., 2015). Additionally, a study by Pilch et al. (2014) also identified that passive perspiration in a low humidity ‘dry’ heated environment, elicits less physiological strain via heat stress than high humidity ‘wet’ heated environment, despite larger BM losses. However, regardless of which method is utilised, excessive hypertonic hypohydration induced via perspiration, can lead to a host of health related issues, such as those described in section 2.7.1 and inclusive of cardiac arrest (Hoey, 1998).

2.7.5. Assessment of Dehydration and Classification of Hypohydration

The assessment of dehydration can be implemented via a variety of methods inclusive of invasive and none invasive techniques as characterised in Figure 2.6, which measure both ICW and/or ECW components, respectively.

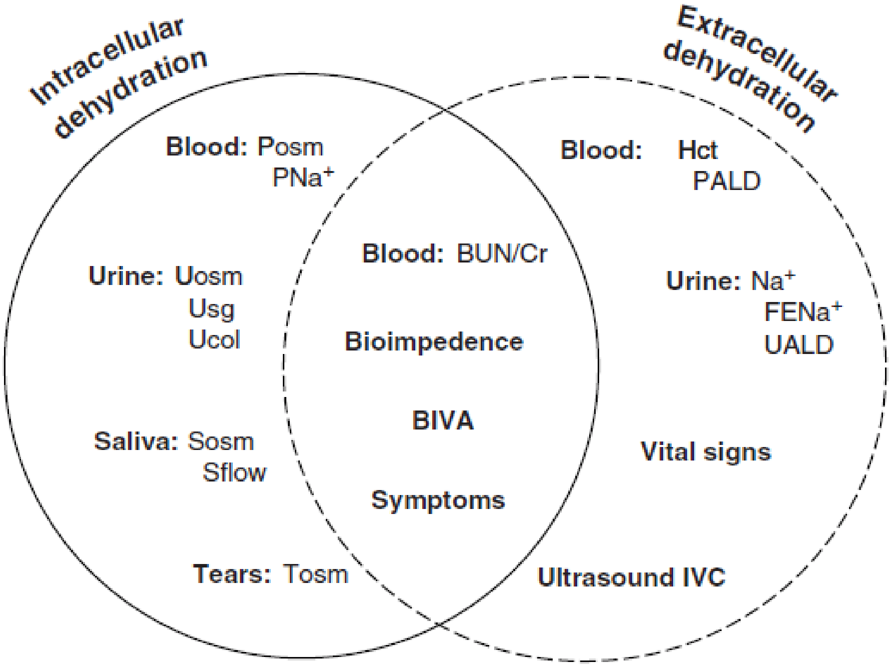


Figure 2.6: *Assessment measures of dehydration*

(Source: Cheuvront and Kenefick (2014)

Posm – plasma osmolality; PNa^+ - plasma sodium; Uosm – urine osmolality; Usg – urine specific gravity; Ucol – urine colour; Sosm – saliva osmolality; Sflow – saliva flow; Tosm – tear osmolality; BUN/Cr – urea/creatinine ratio; BIVA – bioelectrical impedance analysis; Hct – haematocrit; PALD – plasma aldosterone; Na^+ - sodium; $FENa^+$ - fractional excretion of sodium; UALD – urine aldosterone; IVC - inferior vena cava

The most commonly utilised methods within laboratory and field based setting are measurements of BM, TBW via BIA, U_{osm}/sg/col and P_{osm}/Na^+. Sawka et al. (2007) prescribed definitive guidelines for the prescription of dehydration with indicative markers of hypohydration as demonstrated in Table 2.8. However, despite this, an investigation by Hew-Butler et al. (2018), measuring hydration status in a large cohort of collegiate athletes, highlighted that via U_{osm} over 55% of the sample were classified as hypohydrated, yet none met this threshold via PNa^+ indices. Agreement between differing methods specifically examining combat sport athletes, has also shown a wide ranging variability in comparative measurement validity (Fernandez-Elias et al., 2014), with Zubac et al. (2018), highlighting the difficulty in utilising field based methods of assessment (U_{sg}) within this demographic during unstandardized BM loss periods. Armstrong et al. (2016) suggest a blend of methods is best to assess dehydration, yet no clinically established criterion index exists. Despite issues in measurement and established hypohydration values, alarmingly evidence has elucidated that even post weigh in, after a period of rehydration, many combat sport athletes are not sufficiently euhydrated on competition day (Pallares et al., 2016; Pettersson & Berg, 2014).

Table 2.8: *Prescription of dehydration via hypohydration indices*
(Source: adapted from Sawka et al. 2007)

MEASUREMENT	PRACTICALITY	HYPOHYDRATION MARKER
TBW via BIA	Low	>2%
P_{osm}	Medium	>290 $mOsmols \cdot kgH_2O^{-1}$
U_{osm}	High	>700 $mOsmols \cdot kgH_2O^{-1}$
U_{sg}	High	>1.020 $g \cdot ml^{-1}$
BM	High	>2%

2.7.6. Effects on Measures of Performance

There have been numerous reviews and meta analyses, highlighting the detrimental effect >2% of dehydration leading to hypohydration can manifest on general cognitive, strength and endurance based performance measures (Cheuvront & Kenefick, 2014; Savoie et al., 2015; Wittbrodt & Millard-Stafford, 2018). Specifically within combat sport athletes, there have been a number of studies investigating the effects of A/RWL, utilising dehydration methods on both general and specific performance, however results are equivocal. Pallares et al. (2016) investigated the effects of differing hydration statuses (moderately/severely hypohydrated) utilising U_{osm} in 163 combat sport (wrestling, taekwondo, amateur boxing) athletes of both sexes, post weigh in and found that propulsive upper and lower body power were improved in the hypohydrated groups after a 17 hour recovery period compared to the euhydrated control group. Reljic et al. (2016) also studied the effects of >5% A/RWL via dehydration in 28 male combat sport (amateur boxing, judo, taekwondo karate) athletes by assessing aerobic cardiorespiratory capacity via maximal oxygen uptake ($\dot{V}O_{2peak}$) at 3 time points (during training camp, 1-2 days prior to weigh in and in the post competitive period) and found no detrimental effects on performance in comparison to a control group. Artioli et al. (2010c) also highlighted that the effects of >5% A/RWL via hypohydration in a group of 7 judoka on a specific judo related task, manifested no differences compared to a control group, after a 4 hour recovery period. Conversely, Smith et al. (2000) highlighted how 3-4% A/RWL induced by hypohydration, dramatically reduced performance in a group of 7 inexperienced weight cycling amateur boxers in a sport specific task. This observation was also confirmed in another study of 16 amateur boxers by Hall and Lane (2001), who examined the effect of one week >5% A/RWL via hypohydration and observed reductions in specific performance and also profile of mood states (POMS) with increased anger, fatigue and tension concomitant to reduced vigour. Finally an investigation by Degoutte et al. (2006) also examined the effects of >5% A/RWL via combined energy restriction and hypohydration in a group of 20 judoka on a specific judo simulated competitive bout and found reductions in both performance and POMS in comparison to a control group.

Interestingly, there has only been one specific investigation in 10 Taekwondo athletes by Yang et al. (2014), examining the effect of >5% A/RWL loss practices on some of the physical qualities explored in section 2.3 and also a sport specific task. This loss was achieved via a combination of both fasting and dehydrative techniques in a period of 4 days and followed by a 16-18 hour recovery phase. However, yet again results were equivocal given reductions in sport specific performance, yet improvements in general performance i.e. CMJ. Further to this, Yang et al. (2018) also examined the effects of >5% A/RWL BM loss practices on the perceptual and physiological challenges of an opponent based simulation bout in five Taekwondo athletes. Again the recovery period post BM loss was 16 hours and the authors found no negative effects on specific performance or physiological parameters in comparison to a control condition. In conclusion it appears that the method, technique and recovery time period all have a bearing on specific performance post BM reduction via A/RWL strategies. As the weigh in and Taekwondo competitive bouts are typically separated by >16 hours, there may be a reduced detrimental effect given the time period for athletes to recover. This is typically longer than most laboratory based investigations allow who show detriments in performance, yet more well controlled studies are certainly needed (Artioli et al., 2016).

2.8. General Overview of Chronic Body Mass Loss Methods and Psychological and Physiological Effects on Health and Performance

Independent of TBW, both LM and FM are comprised of water and also a number of additional components, that may be assessed via the methods described in section 2.2.1, inclusive of BMC, which can also be modulated in density. All of these tissues are regulated by metabolic processes, controlled by various neuroendocrine interactions. In order to maintain adequate health, it is vital for Taekwondo athletes to compete in the most appropriate weight category in relation to LM. Generally, the loss of FM to maintain a reduced FM%, is initially regarded as the most efficient way to reduce whole BM (Langan-Evans et al., 2011). This reduction in specified tissues can be manifested by creating an energetic deficit, whereby total energy consumed is outweighed by energy expended and this can be achieved by either energetic restriction and/or an increase in energetic expenditure via exercise (Morton et al., 2010). The following sections will serve to examine both of these factors within combat sport and general athletic populations, alongside any positive and negative associations they may incur on both health and performance.

2.8.1. Metabolism During Energetic Deficit – A Brief Historical Overview

The study of energetic modulation has been ongoing since the time of the ancient Greeks, given Aristotle outlined his thoughts on metabolism and recognised that the consumption of food led to heat being produced (Speakman, 2005). Furthermore, Hippocrates observed those who had less FM were predisposed to live longer than those who had greater FM (Schafer, 2005) and in the 17th century Santorio Sanctorius noted the effect of which various activities had on BM regulation (Eknoyan, 1999). The seminal work of Antoine Lavoisier, was the first to formally recognise that respiration of oxygen (O_2) and carbon dioxide (CO_2) is the basis of combustion, which could be measured to assesses energetic metabolism, an idea that was furthered by Justus Liebig who characterised that it was protein (PRO), carbohydrate (CHO) and fat (FAT) substrates, which were utilised during this process (Da Poian et al., 2010). Additionally, Zuntz and Schumberg in their 1901 work *Studien zu einer Physiologie des Marsches*, described how combustion was modulated by metabolic contributions of either FAT or CHO, an ideology which was subsequently updated by Lusk (1924) and termed respiratory exchange ratio (RER). Finally, the work of Francis Benedict and colleagues (Benedict et al., 1919) titled *Human Vitality and Efficiency Under Prolonged Restricted Diet*, highlighted the effects of energetic restriction on metabolism, which coincided with the seminal work and creation of the Harris-Benedict formula for the calculation of resting metabolic rate (RMR) (Harris & Benedict, 1918).

Initial studies on the effects of energetic restriction and/or expenditure began in the late 19th century and were mainly case study reports of total fasting by 'professionals'. Two of the most in-depth case study reports on professional fasting, were conducted by Francis Benedict in 1907 and 1915, with the later giving a full psychological and physiological assessment of the effects on the participant (Benedict et al., 1915). It was not until the middle of the 20th century in the 1940's, that a landmark study by Ancel Keys and colleagues, which became characterised as the *Minnesota Starvation Experiment*, described in detail the psychological and physiological responses in a cohort of male participants who undertook a consistent energetic deficit over a 6 month intervention prior to 3 month pre control and post refeeding periods (Keys et al., 1950). From this outstanding work the foundation of what we now know in regard to energetic deficiency was formed and the findings of this study still inform research and practice to the present day.

2.8.2. Energetic Restriction and Measurement of Energetic Intake

Similarly to the hypothalamic control of the renal feedback loop and thermoregulation, energetic homeostasis is modulated via a balance between intake and expenditure, regulated via the hypothalamus and neuroendocrine tissue/hormonal interactive signals as highlighted in Figure 2.7 (Blundell et al., 2012; Farr et al., 2016). The metabolic interactions that occur during energetic restriction are complex and rarely occur independently of expenditure (which is discussed in section 2.8.3), however this section will focus solely on the mechanisms of restriction.

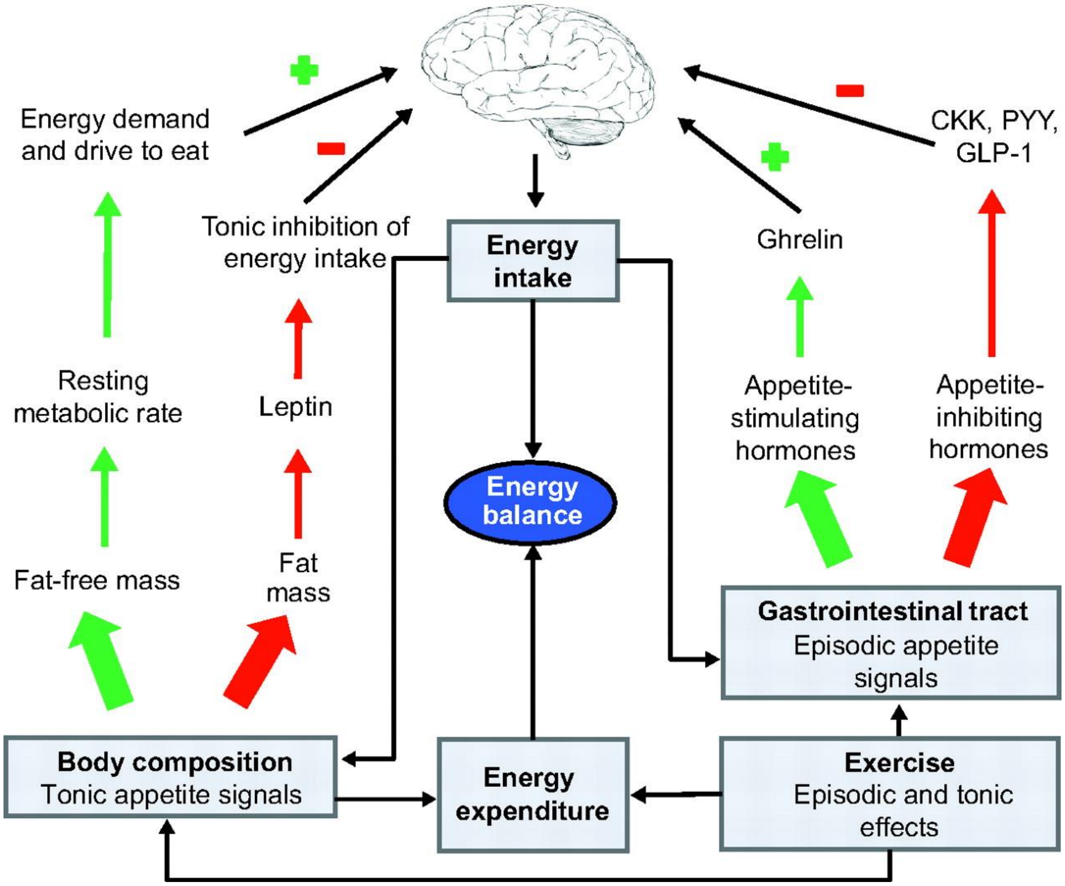


Figure 2.7: *Hypothalamic regulation of energetic homeostasis*

(Source: Blundell et al. (2012)

Figure 2.8 highlights the body composition and endogenous substrate fuel availability of a 70 kg male. If this individual had fed on a mixed meal composition and comprised of 15 kg of FM prior to energetic restriction, they would have 165,900 kcal in storage and 113 kcal in constant circulation (Cahill, 1976). The utilisation of these exogenous fuel stores is regulated by both the time period of energetic restriction, energetic expenditure and the modulation of neuroendocrine factors as highlighted in Figure 2.9.

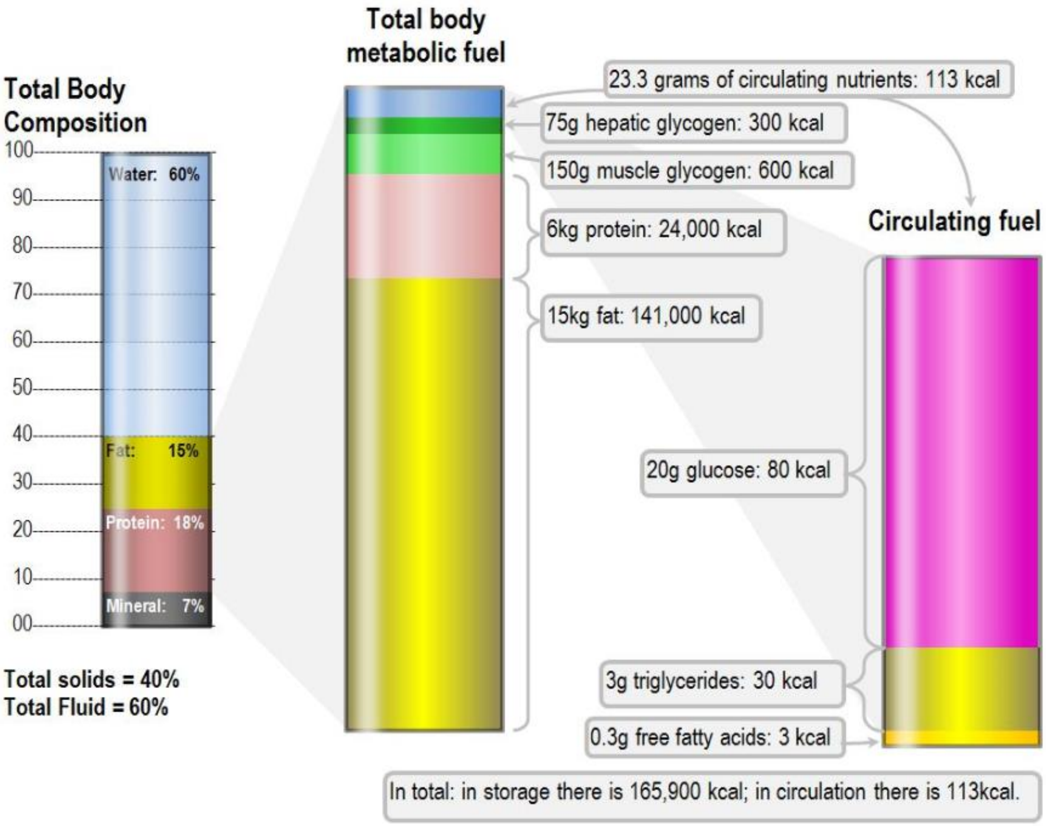
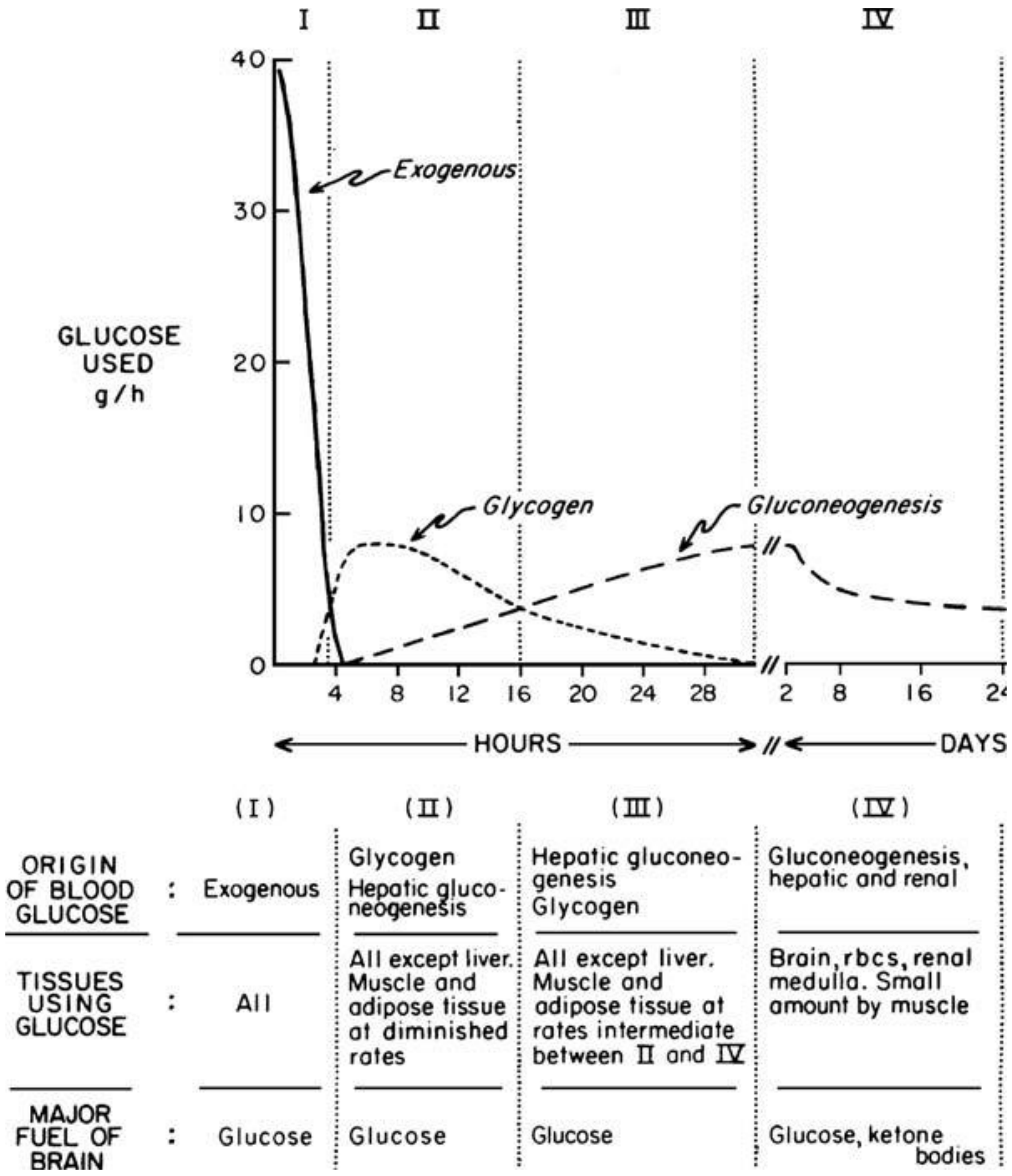


Figure 2.8: *Fuel composition of a Normal Man*

(Source: Yartsev (2018) adapted from Cahill, 1976)

In the initial phase of energetic restriction, a fasting response occurs, whereby in the post absorptive period (3-8 hours dependent on composition and amount), the nutrients generated by the subsequent meal are absorbed in the small intestine (Maughan et al., 2010). At the secondary phase a cascade of neuroendocrine interactions begin to occur (as highlighted in Table 2.9), upregulating both glycogenolysis and lipolysis to utilise endogenously stored substrates via glycolysis and beta oxidation, which are also modulated via energetic expenditure (see section 2.8.3). Enhancement of catecholamine's also upregulates gluconeogenic pathways, in particular via proteolysis, which occurs at around 75 g·day^{-1} (Cahill, 1976). Additionally, the regulation of appetite via both leptin and ghrelin begins, whilst also supporting the interaction of other thyroid controlled hormones (Nymo et al., 2018).



	(I)	(II)	(III)	(IV)
ORIGIN OF BLOOD GLUCOSE :	Exogenous	Glycogen Hepatic gluconeogenesis	Hepatic gluconeogenesis Glycogen	Gluconeogenesis, hepatic and renal
TISSUES USING GLUCOSE :	All	All except liver. Muscle and adipose tissue at diminished rates	All except liver. Muscle and adipose tissue at rates intermediate between II and IV	Brain, rbcs, renal medulla. Small amount by muscle
MAJOR FUEL OF BRAIN :	Glucose	Glucose	Glucose	Glucose, ketone bodies

Figure 2.9: *Exogenous/endogenous substrate fuel utilisation in the post absorptive, fasted and semi starved state.*

(Source: Cahill, 2006)

In prolonged periods of energetic restriction lasting beyond 48 hours, when glycogen and glucose stores have been depleted, gluconeogenesis predominantly provides fuel via hepatic and renal regulation of both glucose and ketones (Cahill, 2006). It is at this stage a reduction in RER and a condition known as adaptive thermogenesis (AT) begins to occur (discussed further in section 2.8.5). Evidence from Steinhauser et al. (2018) has also characterised circulating metabolomes during a 10 day period of complete energetic restriction in healthy males and highlighted that hypoleptinemia contributes largely to the shift from glucose to lipid fatty acid metabolism.

Table 2.9: *Endocrine response to energetic restriction*
(Source: adapted from Finn and Dice (2006)

HORMONE	**REGULATION DURING ENERGETIC RESTRICTION**	**EFFECT ON TISSUES**
Insulin	Decreased	↑blood glucose via glycogenolysis,, proteolysis, lipolysis ↓proteogenesis
Glucagon	Increased	↑glycogenolysis, gluconeogenesis
GH	Increased	↑lipolysis
IGF-1	Decreased	↓proteogenesis ↑proteolysis
Testosterone	Decreased	↓proteogenesis ↑proteolysis
Glucortocoids	Increased	↑, proteolysis, lipolysis, gluconeogenesis
T_3 and T_4	Decreased	↓RMR reducing need for lipolysis and proteolysis
Leptin	Decreased	↓Energetic expenditure, thyroid hormone production ↑lipolysis, glucose homeostasis
Ghrelin	Increased	↑Appetite, ↑lipolysis via growth hormone (GH)

There is a wide body of research demonstrating a number of positive associations with energetic restriction in the absence of undernutrition (Most et al., 2017). There have been a number of studies highlighting the positive associations of energetic restriction on prolonging the lifespan of varying mammalian and non-mammalian species (Balasubramanian et al., 2017), inclusive of humans (Ravussin et al., 2015). Additionally the Biosphere 2 studies of the early 1990’s, elucidated a number of additional health benefits, when the study participants were forced into an unanticipated EI reduction of 30%, inclusive of adequate PRO and dietary fibre, yet low in FAT. There were associated improvements in cardiovascular health via reductions in blood pressure, cholesterol and triglycerides (Walford et al., 1992), maintenance of endocrine hormones within reference ranges, whilst undergoing significant energetic expenditures and with no effect on psychological health (Walford et al., 2002). Additionally it also appears that energetic restriction may provide a potent stimulus to enhance cardiorespiratory performance via increases in mitochondrial biogenesis, albeit in a rodent model (Marosi et al., 2018).

Despite these enhancements, it remains to be seen that energetic restriction with undernutrition can cause a range of health and performance related issues. Firstly it is important to understand how undernutrition is defined, with Shetty (2006) describing this as: ‘an inadequate intake of dietary energy, regardless of whether any other specific nutrient is a limiting factor’. As described earlier, the seminal work of the *Minnesota Starvation Experiment* classified how a reduction of EI by 40% over a period of 6 months resulted in remarkable negative impacts on both psychological and physiological health and performance. However, it should be noted that the diet utilised in this study was incredibly low in key macronutrients (PRO <0.8 $g \cdot kgBM^{-1} \cdot day^{-1}$) concomitant with low intakes of fruits and vegetables. This also raises the point of what EI value and macro/micronutrient composition represents the critical threshold of undernutrition? One proposed hypothesis is that if the energetic restriction represents an EI providing the requirement of at least resting metabolic rate (described in section 2.8.3), this will result in a homeostatic balance via utilisation of endogenous stores independent of undernutrition associated issues (Stiegler & Cunliffe, 2006). This ideology has been tested in a number of athletic investigations inclusive of making weight sports (Morton et al., 2010; Wilson et al., 2012; Wilson et al., 2015) and appears to hold true when exercise energy expenditures are not too excessive.

The measurement of energetic restriction requires a valid, accurate and reliable assessment of EI, which is often regarded as one of the most difficult areas of sport and exercise science due to the variability in methods, the potential for error, participant engagement and researcher analysis (Hackett, 2009). A number of systematic reviews (Capling et al., 2017; Poslusna et al., 2009), highlight a large variability with frequent exhibition of over and underreporting between established methods, such as food diaries and 24 hour dietary recall, whilst (Basiotis et al., 1987) report the large timescales required to gain defined confidence employing these methods in both individual and group EI measurement. Another study has shown the potential of electronic dietary intake assessment methods such as 'Snap-N-Send', which may aid in this issue, yet further research is needed to validate this method with a number of athletic populations (Costello et al., 2017). There is a paucity of research examining EI in combat sport athletes, particularly during energy restriction. Boisseau et al. (2005) highlighted significant reductions in EI (2076 ± 206 - 1666 ± 156 $\text{kcal}\cdot\text{day}^{-1}$) and key macro/micronutrients across a three week measurement period. Kasper et al. (2018) demonstrated a phased reduction in EI (1900-1000 $\text{kcal}\cdot\text{day}^{-1}$) in a professional MMA athlete across an eight week measurement period. Additionally, the EI of Taekwondo athletes in general is sparse. Three studies have examined EI during energetic balance (Cho, 2014; Cho et al., 2013; Rossi et al., 2009) with only two studies during energetic restriction and all confined to FD assessments. Both Fleming and Costarelli (2007) and Papadopoulou et al. (2017), showed reductions in EI (35-48%) via energetic restriction in their respective cohorts of athletes, resulting in significant depletion of key macro and micronutrients.

2.8.3. Energetic Expenditure and Measurement within Taekwondo Activities

As described in section 2.8.2 another key regulator of metabolic homeostasis is energetic expenditure (EE) which comprises of RMR (divided into sleeping and awake cycle components), non-exercise activity thermogenesis (NEAT), diet induced thermogenesis (DIT – also termed the thermic effect of food or 'TEF'), activity energy expenditure (AEE) and excess post oxygen consumption (EPOC) (Ravussin et al., 1986). Collectively, all of these total energy expenditure (TEE) components require the liberation of energy from exogenous and endogenous stored substrates, in order to fuel their respective primary functions. RMR (also coined *basal metabolism*), is the energy required to maintain cellular, organ and central nervous system homeostasis, which contributes the largest portion of overall TEE at approximately 60-70% (Carpenter et al., 1995) and is dependent upon numerous factors inclusive of sex, age, ethnicity and the respiration rates of specific tissues and organs (McClave & Snider, 2001). DIT is the process required to combust exogenous substrates via digestion/absorption and also endogenous storage (Quatela et al., 2016). Each nutritional substrate has an individual DIT contribution, requiring 0-5% for FAT, 5-10% for CHO and 20-30% for PRO (Westerterp, 2004), which generally equates to 10% of a mixed meal composition extended across a 6 hour post prandial period (Reed & Hill, 1996). Ethanol induced thermogenesis (EIT) also contributes 10-30% of ingested alcohol substrate (Suter et al., 1994). NEAT, AEE and EPOC are the most variable components of TEE given they are modulated by the energy required to conduct muscular contraction, respiration and cardiovascular function for postural kinaesthesia, proprioceptive locomotion and to resist external forces (Ravussin et al., 1986). Additionally, the true 'net' estimation of AEE (exercise energy expenditure – EEE) should be calculated by subtracting the other components of TEE, inclusive of RMR and NEAT during the period of exercise activity (Fagerberg, 2018). Many studies often neglect to take this into consideration and utilise calculations of 'gross' AEE which may over represent the metabolic cost of specific exercise activities and confound other calculation i.e. energy availability and within daily energy balance (addressed in section 2.8.4) (Loucks, 2014). A final consideration is also the manipulation of TEE and AEE substrate utilisation via both exercise and dietary modulation. Classical research has highlighted that FAT and CHO utilisation has a reciprocal relationship with both exercise duration and intensity (Romijn et al., 1993; van Loon et al., 2001). Additionally, numerous research investigations have demonstrated commencing exercise with varying levels of exogenous and also endogenous substrate, can have pronounced effects on both exercise (Coyle et al., 1997; Horowitz et al., 1997; Vieira et al., 2016) and daily (Iwayama et al., 2017; Iwayama et al., 2015; Robinson et al., 2015; Wallis & Gonzalez, 2018) substrate oxidation. This is an important consideration for combat sport athletes in particular for the modulation of specific tissue losses as highlighted in section 2.8 and in tandem with energetic restriction i.e. fasting as highlighted in section 2.8.2.

As further described in section 2.8.2, all of these respective TEE components produce heat via combustion during respiration, resulting in both aerobic and anaerobic metabolic processes. The measurement of TEE and individual components, can be achieved via a number of methods, all of which differ in practicality, validity, accuracy and reliability and can be divided into calorimetric (direct and indirect) or non-calorimetric based techniques (Levine, 2005). The criterion method, which can measure all the components of TEE simultaneously/individually and across extended time periods is direct calorimetry. Direct calorimetry works on the principle of measuring both heat exchange and respiration within an enclosed chamber, however, the cost of this technique (>£1,000,000) and also the restrictions of normal daily living/training activities, due to the confined space within the calorimeter, do not make this method conducive for effective use in athletic populations (Kenny et al., 2017). Secondary to direct calorimetry, doubly labelled water (DLW) is a non-calorimetric technique, which requires the ingestion of water (H_2O), where the H and O elements have been labelled with the stable non-radioactive isotope deuterium (D_2O^{18}). The method then analyses the rate of D_2O^{18} elimination in urine, in order to assess CO_2 production and calculate energetic expenditure (Westerterp, 2017). Again, whilst this method provides a high degree of validity, accuracy and reliability of measurement, it only provides TEE during an entire measured time period i.e. days/weeks so cannot be utilised to assess individual components (Levine, 2005).

Indirect calorimetry calculates EE on the principle of combustion through inspiration and expiration of O_2/CO_2, via an open circuit metabolic system, which can be equipped with a canopy hood or face mask for measurement of RMR, D/EIT, AEE/EEE and EPOC, respectively (Schoffelen & Plasqui, 2018). Indirect calorimetry is the most widely used method of EE measurement, given that metabolic cart units are relatively cost efficient (£10,000-50,000) and can be used for a host of activities to assess AEE, inclusive of portable based systems in the field (MacFarlane, 2017). Following both direct calorimetry and DLW, indirect calorimetry is regarded as the criterion method for the assessment of AEE/EEE (Ndahimana & Kim, 2017). However, one major drawback of this method is that it is relies solely on measurements of aerobic metabolism and ignores the contributions of anaerobic metabolism (Panissa et al., 2018), which can often result in underestimation as anaerobic metabolic responses may quantify a significant portion of AEE/EEE measurement, particularly in intermittent exercise (Scott, 2005).

Neither direct calorimetry or DLW have ever been utilised within a Taekwondo athletic demographic, with most TEE and/or AEE measurements being examined via indirect calorimetry. The first study to assess AEE in Taekwondo based activities within a 20 minute dynamic session, employed portable indirect calorimetry and the kcal equivalent of 5 $kcal \cdot LO_2^{-1}$, which exhibited gross AEE calculations of 14.3 ± 1.8 $kcal \cdot min^{-1}$ (286.5 ± 35.6 kcal) and 10.1 ± 2.0 $\mathrm{kcal \cdot min^{-1}}$ (201.6 ± 39.1 kcal) in advanced practitioner males and females, respectively (Toskovic et al., 2002). A number of laboratory based studies have also investigated AEE in simulated protocols of Taekwondo bouts, with methods employed to consider both the aerobic and anaerobic metabolic components. This is achieved via the inclusion of anaerobic ATP/PCr (measured by the fast component of EPOC via bi or monoexponential curve method) and glycolytic (by measuring ΔBLac change between time periods) contributions, whereas aerobic contributions are calculated by subtracting resting O_2 from exercise O_2 values and calculating the area under the curve via the trapezoidal method (Artioli et al., 2012). Utilising opponent based simulated bouts (as highlighted in section 2.4.3), Campos et al. (2012); Lopes-Silva et al. (2018); Lopes-Silva et al. (2015) generated complete AEE values ranging from 37-38 kcal in round 1, 39-44 kcal in round 2 and 40-49 kcal in round 3, resulting in 116-131 kcal across an entire bout. Whilst all of these studies provide useful data on the AEE demands during specific Taekwondo based activities, they are not available for use without specialist expertise or equipment and also the ecological validity issues raised in section 2.4.3. Additionally, due to the participant needing to wear an indirect calorimeter, these studies only include AEE calculations of non-contact based simulated bouts, which is an inherent competitive element of the sport. Efforts to solve this problem have been made by creating a portable indirect calorimetry system embedded into protective Taekwondo headgear (Hausen et al., 2017), however the additional mass carriage may further confound the accuracy of the AEE measurement (Sparks et al., 2013).

The use of portable actigraphy as another non-calorimetric method, is becoming increasingly popular when examining AEE in a host of free living and physical activities (Shephard & Aoyagi, 2012). Portable actigraphy with integrated HR and accelerometry units, have been highlighted as the most accurate in conjunction with the aforementioned criterion methods (O'Driscoll et al., 2018), making this ideal for use with athletic populations. A limited number of studies have utilised this technology with a Taekwondo athletic demographic for TEE, NEAT and AEE estimations (Cho, 2014; Cho et al., 2013). However, the portable actigraph used in these studies was a hip worn accelerometer, which does not take into account whole body movements, nor has this device been successfully validated against either DLW or indirect calorimetry (Brazeau et al., 2014; Correa et al., 2016; Dannecker et al., 2013; Johnson et al., 2015). It is clear that more practical methods, which are valid, accurate and reliable, are required for the measurement of AEE in Taekwondo and combat sport populations. This becomes increasingly important when the consistent examination of both energetic intake and expenditure are needed to assess the potential to create an energetic deficit for loss of specified BM tissues. The following section will examine methods explored in section 2.8.2 and those within this section, which can highlight energetic balance and how this can be utilised to consider subsequent health and performance consequences of making weight.

2.8.4. Energy Availability and Within Daily Energy Balance

A holistic 24 hour view of energy intake and expenditure (EB), is typically utilised to examine energetic homeostasis. However, to assess a wider scope of the interplay between energetic intake and expenditure a number of concepts have arisen in order to give a more global view of this paradigm. In the early 1990’s, Loucks and Callister (1993) proposed a new ideology classified as energy availability (EA), which is calculated as: *EI – EEE/FFM.* This was defined to examine the relationship between EI and EEE, where either factor maybe increased/decreased and can define specific thresholds of EA. Loucks (2004) and Loucks et al. (2011) proposed the following thresholds based on a series of laboratory controlled trials, albeit predominantly in females:

- **>45 kcal·kg·FFM·day^{-1}** *equals energy balance and is recommended to maintain adequate energy for all physiological functions i.e. energetic homeostasis*
- **30-45 kcal·kg·FFM·day^{-1}** *is suggested as a tolerable range for athletes aiming for BM loss as part of a constructed dietary and exercise intervention over a defined time period*
- **<30 kcal·kg·FFM·day^{-1}** *is classified as low energy availability (LEA) and suggests an unsafe energy level for optimal bodily function, which may lead to unfavourable health outcomes and sports performance*

(Adapted from Logue et al. (2018)

In the case of LEA, this is postulated to lead to symptoms of TRIAD and/or RED-S, both of which are discussed in depth in section 2.8.5. However, despite the wider scope of assessment beyond holistic EB, measurement of EA status requires precise measurements of FFM, EI and EEE (as described in the previous sections), in order for prescription to be accurate and this is often fraught with complication (Burke et al., 2018b; Loucks, 2014). An additional ideology (see Figure 2.10) characterised as Within Daily Energy Balance (WDEB) was created to assess the total daily 24 hour fluctuations, which take into account the endocrine interactions on energy homeostasis (Benardot, 2013). The method also examines perturbations in anabolic (>400kcal), catabolic (<400kcal) or balanced (<400 - >400kcal) hour by hour time phases, to categorise the interactions between EI and EEE throughout a measurement period. Torstveit et al. (2018) proposed a WDEB method, which considers both EI and TEE across a complete 24 hour by hour period and is cumulatively added to subsequent measurement periods i.e. each day to day. The method (as described in section 7.2.7) utilises EEE, NEAT, RMR, EPOC and E/DIT estimations to calculate total energy expenditure (TEE) and in conjunction with EI calculate WDEB.

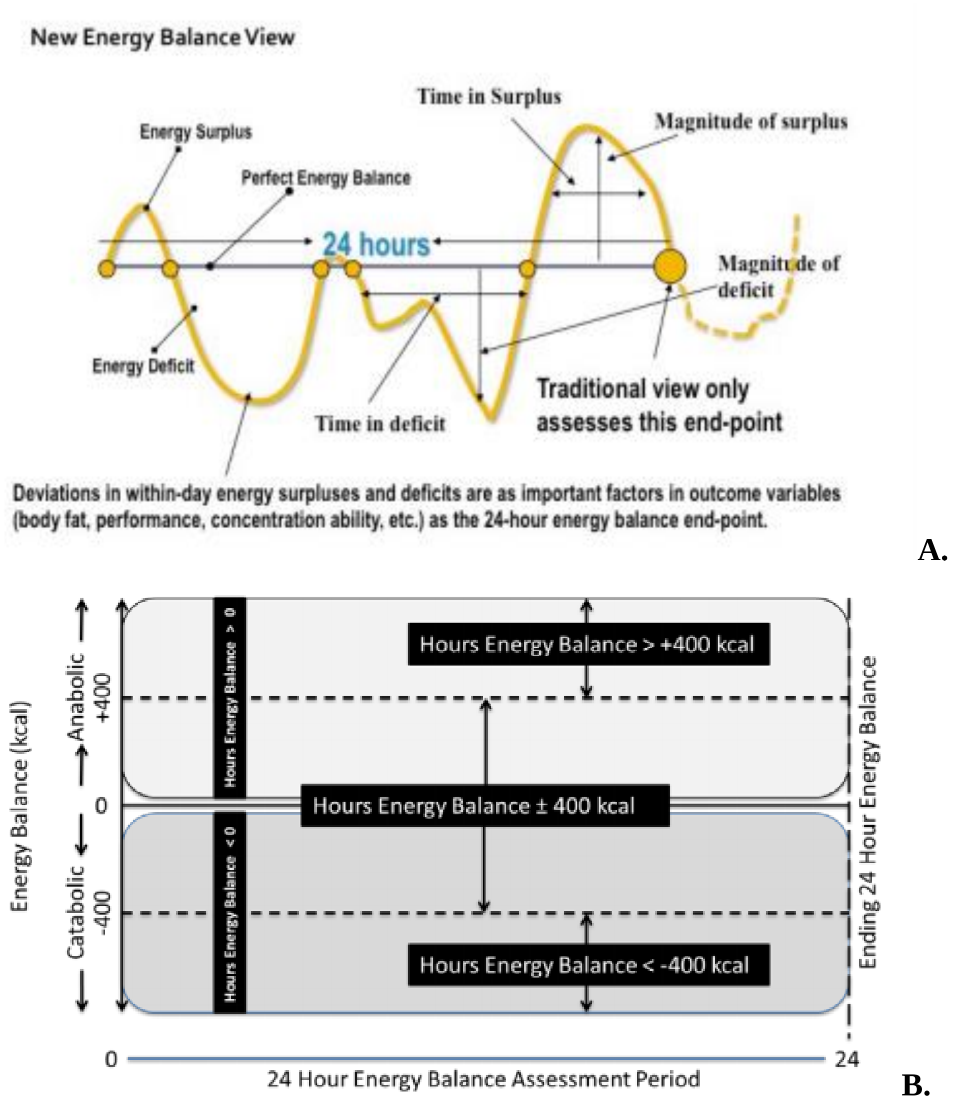


Figure 2.10: (*A.) WDEB view of 24 hour by hour energy balance inclusive of time/magnitudes of deficit and/or surplus energy status (B.) WDEB anabolic, catabolic and balanced fluctuations*

(Source: Bernadot, 2013)

2.8.5. *Health and Performance Effects of Energetic Deficiency: Relative Energy Deficiency in Sports (RED-S)*

Since the 1980's, the effects of prolonged energetic deficit were recognised to have detrimental effects, particularly in females and in 1992 was characterised as the Female Athlete Triad (TRIAD) at an American College of Sports Medicine (ASCM) annual meeting (Yeager et al., 1993). In 2014 an IOC position stand classified a new concept known as Relative Energy Deficiency in Sports (RED-S), with a model inclusive of additional health and performance related factors, that also included the effects of energetic deficit to include both sexes (Mountjoy et al., 2014). In the same year a large group of authors who supported the TRIAD model, published an article refuting RED-S (De Souza et al., 2014), which was rebutted in the following year (Mountjoy et al., 2015). In 2018, the RED-S model received an update to include a wider breadth of research examining the syndrome and has become synonymously accepted as the way to examine the health and performance consequences of LEA in athletes (Mountjoy et al., 2018).

RED-S is classified by 10 health and performance related consequences, as highlighted in Figure 2.11. However, despite the ideology of the model, many of the areas have limited research supporting any proposed outcomes, in particular cardiovascular and gastrointestinal factors. Additionally, there is still a paucity of research examining the effects of LEA on RED-S in male populations and particularly in combat sport athletes. Burke et al. (2018a) acknowledge that given the aforementioned practices of combat sport athletes, they may be highly susceptible to RED-S and more research is warranted. The only study which has examined energy deficiency in a combat sport *per se*, was a case study investigation, highlighting the health and performance consequence in a professional male MMA athlete over an eight week ‘phased’ competitive preparation period (Kasper et al., 2018). No study has ever examined RED-S syndromes in a Taekwondo population and given the practices employed by this demographic as highlighted in section 2.6.6, there may certainly be a precedent for LEA leading to RED-S and an investigation into this is certainly warranted.

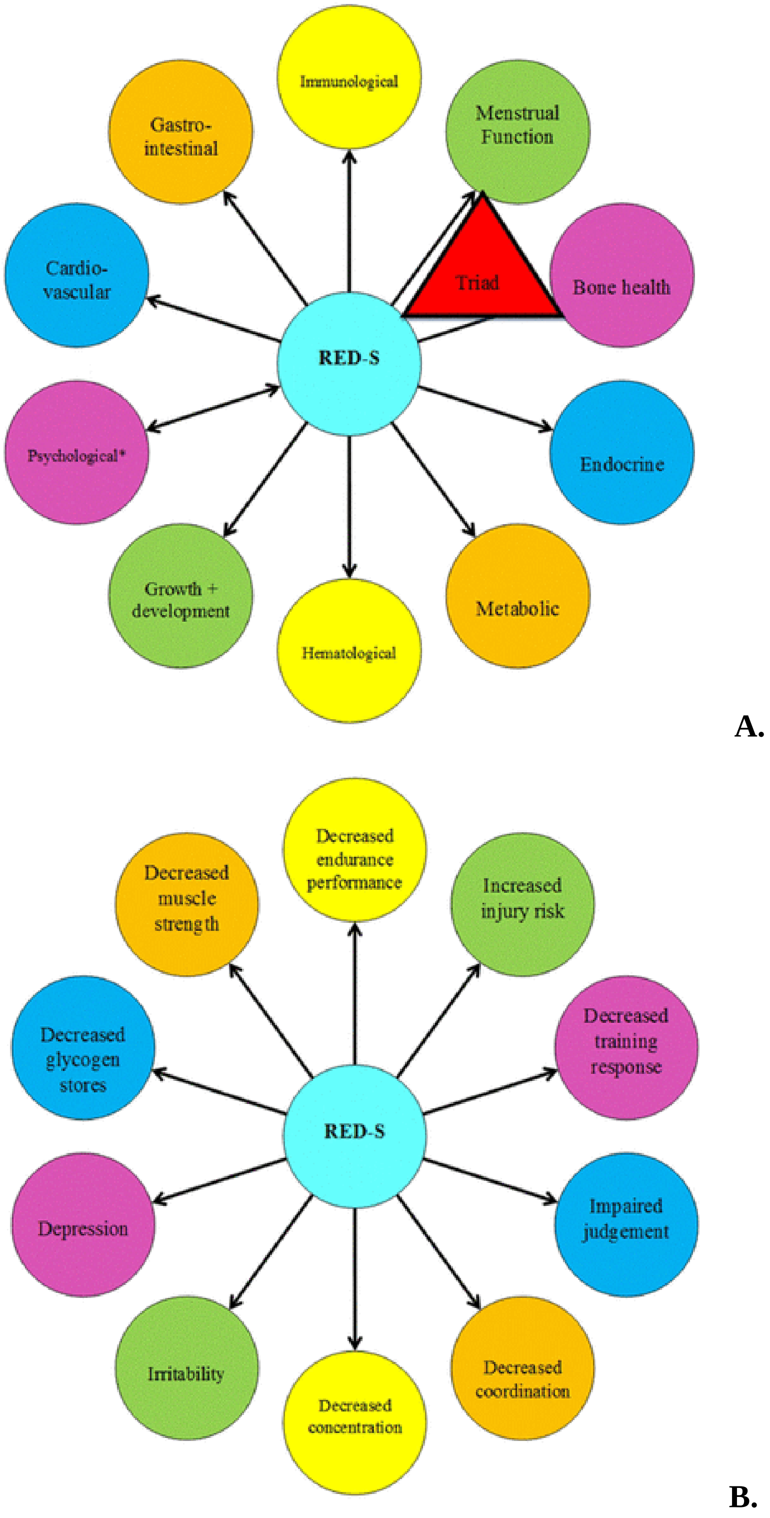


Figure 2.11: *The health (A.) and performance (B.) consequences of RED-S*

*Psychological consequences can either precede RED-S or be the result of RED-S

(Source: Mountjoy et al., 2018).

Reductions in LM: A typical symptom of RED-S may be a reduction in BM and in particular LM. Despite the raft of aforementioned studies examining body composition of Taekwondo athletes in section 2.2.1, there are few which have examined changes in this tissue during prolonged periods of energetic deficit. However, interpretation of LM changes in combat sport athletes (particularly grappling disciplines), should be considered with caution given reductions in LM may be artefacts of dehydration within LM tissue compartments i.e. when pre standardisation is not considered (see section 2.2.1). Kukidome et al. (2008) examined making weight practices in wrestlers across a 1 month competitive period and found no changes in body composition measured by magnetic resonance imaging (MRI) until 1 week prior to weigh in. In this period, there were significant reductions in BM (<5.4 kg) and LM (<3.6 kg) as result of a loss in TBW (-5.9%) and independent of a 21% reduction in EI. This was also confirmed by Silva et al. (2010) in a cohort of judo athletes, where total reductions of BM (5.8-6.2%) were achieved via losses in TBW via ICW, independent of reductions in body composition tissues measured via DXA. A conclusive study by Kondo et al. (2018), highlighted in a cohort of wrestlers that a 6.4% decrease in BM resulted in a significant loss of LM as measured by three and four compartmental DXA/DLW methods, but this could mainly be attributed to a 71% reduction in TBW from baseline. Despite a significant decrease in EI and energy density, the authors concluded that the extreme energetic restriction employed by many combat sport athletes in the acute phase of BM reduction is redundant, given that losses of FM are generally minimal.

Despite this, chronic periods of energetic deficiency can result in losses of LM via reductions in contractile protein synthesis and increases in degradation, stimulated via proteolysis. Morton et al. (2010) described in a case study intervention undertaken by a professional boxer, losses of 4.5 kg LM measured via DXA whilst maintaining an EI equivalent to RMR. Studies by Nindl et al. (1997) and Friedl et al. (2000), highlighted in cohorts of US Army Rangers across eight week training periods, that a decrease in EI below RMR (eliciting an energy deficit of <1000kcal/day for four intermittent 7-10 day periods), resulted in remarkable losses of both BM (<8 kg) and LM (<5 kg) measured via DXA. However, it should also be noted that all the studies described so far incorporated

EI that were reduced in dietary PRO content. Given that there is substantial evidence highlighting that an intake of >2 g·kg·BM^{-1} can reduce losses of LM during energetic deficit (Areta et al., 2014; Longland et al., 2016; Mettler et al., 2010; Pasiakos et al., 2013), this may be a useful tool in combating the associated losses of LM during RED-S. This intervention has been employed in making weight athletes from both combats sport (Kasper et al., 2018) and horse racing (Wilson et al., 2015), who coupled higher dietary PRO intakes with resistance exercise. However, Martin-Rincon et al. (2018) (albeit in an obese cohort during a limited time period) suggests that during extreme energetic deficit, higher PRO intakes do not enhance contractile protein synthetic responses, which is due in part to neuroendocrine interactions, with the associated maintenance of LM attributed to mechanical stimulus of contractile muscle actions (Calbet et al., 2017). However, a systematic review by Helms et al. (2014) suggests that any increase in energetic restriction must be met reciprocally by higher dietary PRO intakes, and this is supported in an investigation conducted by Hector et al. (2018).

Neuroendocrine disturbance: One key indicator of RED-S is a disturbance in neuroendocrine regulation, exhibiting values outside of normal reference ranges (see Figure 2.12). In both sexes, LEA generally has a negative effect on EI related hormones (adipokines, ghrelin), insulin, growth hormone (GH), insulin-like growth factor (IGF-1), thyroid hormones (triiodothyronine - T_3 and thyroxine - T_4) and catecholamines (cortisol) (Elliott-Sale et al., 2018). Sex specific responses are seen on the hypothalamic–pituitary–gonadal axis, which is regulated by oestrogen in females and testosterone in males, for control of reproductive and immune functions, with LEA generally resulting in hypogonadism (Tenforde et al., 2016). The contribution of endocrine interaction on amenorrhea during TRIAD in females is well characterised (Gordon et al., 2017), yet in males this is largely not understood in contributing to RED-S (Burke et al., 2018a). Muller et al. (2015) highlighted significant reductions in thyroid, gonadal, insulin and leptin hormones in an LEA period of 3 weeks concomitant with reductions in BM (<6 kg) and LM (<55%). Nindl et al. (1997) and Friedl et al. (2000), also demonstrated pronounced effects on gonadal and thyroid endocrine markers after a prolonged eight week period of energetic deficit, again coupled by substantial losses of both BM and LM.

In combat sport athletes a number of studies have examined periods of energetic deficit, albeit in shortened timeframes. Degoutte et al. (2006) highlighted a reduction in both testosterone and insulin in only 1 week of A/RWL, induced by energetic deficit amongst a group of judoka vs. controls who remained stable at baseline levels. Strauss et al. (1985) showed significant reductions in testosterone in a group of wrestlers across a competitive season, with greater reductions associated with decreases of both BM and FM. In another study of wresters, Karila et al. (2008) highlighted that a 3 week period of energy deficit induced significant effects on gonadal hormones, with large changes in testosterone (<63%), luteinizing hormone (LH) (<54%) and sex hormone binding globulin (SHBG) (>40%). One of the most compelling investigations to examine endocrine interactions during energy deficit in a combat sport case study report was the aforementioned study by Kasper et al. (2018). Across a prolonged period of eight weeks there were significant alterations to gonadal hormones with testosterone falling to a low of 1.4 $\text{nmol}\cdot\text{L}^{-1}$, well outside normal reference ranges. To date no investigation has ever examined the neuroendocrine interaction of RED-S in Taekwondo athletes.

Metabolic homeostasis imbalance: Another key indicator of RED-S is the effect on metabolic rate, whereby RMR decreases concomitantly to reductions in energetic deficit and LM (Grande et al., 1958). However, an additional RMR suppression termed *adaptive thermogenesis* (AT), may also occur via a lowering of the metabolic respiration of specific body tissues, independent of proteolytic reductions of LM (Muller & Bosy-Westphal, 2013; Rosenbaum & Leibel, 2010) and parallel to decreases in homeostatic temperature (Muller et al., 2015). Utilising assessments of measured RMR (RMR_{meas}) and predicted RMR (RMR_{pred}), a ratio of RMR ($\text{RMR}_{\text{ratio}}$) suppression can be calculated by subtracting these values i.e. $\text{RMR}_{\text{ratio}} = \text{RMR}_{\text{meas}} – \text{RMR}_{\text{pred}}$ to examine instances of AT. Both Staal et al. (2018) and Torstveit et al. (2018), indicate an $\text{RMR}_{\text{ratio}}$ of <0.90 can be employed to define instances of metabolic suppression, indicating potential energy deficiency. However caution must be taken in the consideration of which predictive equation is utilised, given the potential for significant underestimation in athletic populations (Jagim et al., 2018).

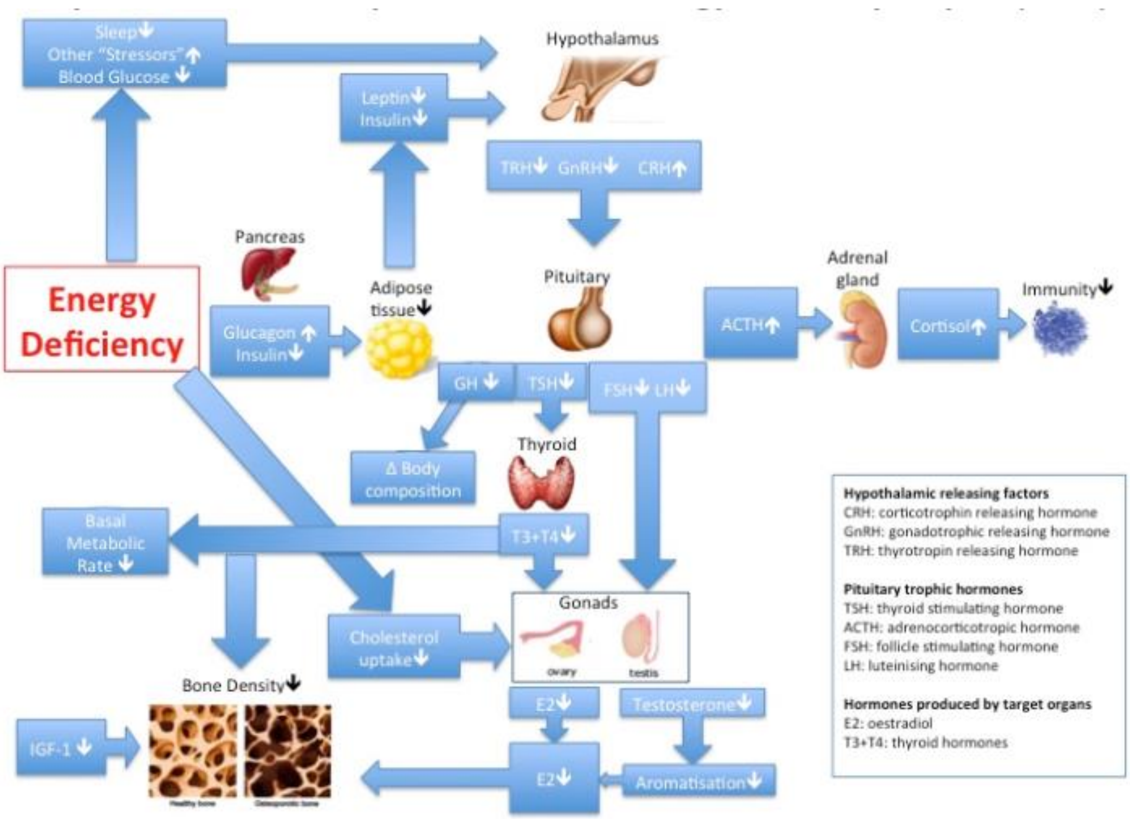


Figure 2.12: *Energy deficiency interaction on endocrine system regulation of RED-S health consequences*

(Source: (Keay, 2017)

Instances of AT have been well characterised in the literature most notably in the *Minnesota Starvation Experiment*, whereby there was a 39% reduction in RMR, of which 35% was equated to AT (Keys et al., 1950). A repeat of this study design by Muller et al. (2015) also showed similar trend in a much shorter time period of only three weeks, with substantial RMR suppression of which 48% was attributed to AT. However, the assessment of suppressed RMR in combat sport athletes is limited, with no investigations in Taekwondo and the majority of studies on wrestling athletes showing equivocal results (Schmidt et al., 1993; Steen et al., 1988). Kasper et al. (2018), highlighted reductions in RMR across an eight week training period, which only became pronounced when the athlete adjusted to an EI below that of RMR in the fourth week of assessment.

Immunological deficit: The effects of energy deficiency on immunity within athletic populations is not every well understood, with a paucity of research examining this area (Mountjoy et al., 2018). However, it is well established that energy deficiency, in particular reduced EI, can downregulate immune responses (Ritz & Gardner, 2006; Walsh, 2018) via the hypothalamic-pituitary-adrenal axis, which is mediated by a number of stressors. Increases in energy deficiency can be a potent stressor on this system, releasing a cascade of neuroendocrine hormones, thereby dampening immune function, with the psychological stresses of reduced EI also possibly playing a role in this paradigm (Edwards et al., 2018). In combat sports, immunity during energetic deficit has been studied predominantly in judoka with increases in pro inflammatory cytokines (Abedelmalek et al., 2015), immunoglobulins (Umeda et al., 2004) and neutrophil phagocytic activity (Kowatari et al., 2001) across periods of 7-20 days. Tsai et al. (2011a); Tsai et al. (2011b) examined 10-16 male and female Taekwondo athletes undergoing energetic deficits across 4-7 week training periods and noted this dramatically reduced markers of both salivary and mucosal immunity and with increases in the reported incidences of upper respiratory tract infections.

Bone turnover disturbance: It is widely accepted that energy deficiency via LEA has pronounced negative effects on rates of bone turnover, particularly females diagnosed with TRIAD (Mountjoy et al., 2018). The measurement of bone health is commonly examined via DXA BMC/D assessment, however, there is debate about the effectiveness of this method to evaluate both 'true' BMC/D. As DXA only measures in a two dimensional image and bases both BMC/D on bone area rather than volume, the method can only account for approximately 60% of the actual changes in bone tissues over repeated timescales (Seeman, 1998). On this basis, bone turnover biomarkers (β-carboxy-terminal cross-linked telopeptide - β-Ctx, total procollagen type 1 N-terminal propeptide - P1NP) provide a much better view of the acute metabolic interaction on the modulation of bone structure. Some studies conducted on actively trained individuals have shown a supressed P1NP/ β-Ctx ratio, in favour of bone reabsorption during acute periods of LEA and energetic deficit in both sexes (Papageorgiou et al., 2017; Zanker & Swaine, 2000), although results in male populations are equivocal. However, a review by Papageorgiou et al. (2018) states that the majority of studies highlighting potential bone turnover reduction, have been completed on athletic groups with minimal osteogenic stimulus, which may offset the potential for bone formation. Whilst there are limited studies in combat sports (and none in Taekwondo athletes) on the effects of energy deficiency via LEA on bone turnover, it appears that the mechanical loading exhibited in the various grappling and striking disciplines may provide a potent osteogenic stimulus, which may offset any negative effects in both adolescent and adult athletes (Ciaccioni et al., 2017; Nasri et al., 2015; Prouteau et al., 2006).

Perceptual and psychological effects on health and performance: Finally, there have been a number of studies conducted in combat sports demonstrating that periods of energetic deficit have a detrimental effect on perceptual and psychological markers of health and performance, which is key indicator of RED-S. A study by Hall and Lane (2001) on amateur boxers, highlighted reductions in performance on a simulated boxing related task coupled with a decrease in psychological POMS. This has also been replicated in judoka (Degoutte et al., 2006; Filaire et al., 2001; Koral & Dosseville, 2009) and Wrestling (Horswill et al., 1990; Webster et al., 1990), where the impact of energy deficiency in both acute and chronic time periods was assessed and found to have a negative effect on a number of physiological performance, simulated tasks/protocols and POMS markers. This has led to studies conducted in combat sports assessing the differences between chronic/gradual and A/RWL on a range of health and performance based markers. A study by Fogelholm et al. (1993), highlighted no differences between acute and chronic making weight methods on a range of performance tests in a group of grappling athletes. Conversely to this, Yang et al. (2014) demonstrated in a randomised crossover study, improved perceptual and physiological performance between a gradual reduction in BM across four weeks vs A/RWL achieved in four days in a group of elite level Taekwondo athletes. Given the context of section 2.6.7, this makes sense given the inherent practices of these two athlete groups.

To summarise, the psychological and physiological regulation of chronic BM loss methods are both extremely diverse and complex. The measurement of these factors needs to be carefully considered, in order to accurately assess and diagnose the potential for LEA leading to RED-S consequences, which in turn can cause substantial health and performance effects. The final section of this review will now examine the effects of recovery from energy deficit before summarising the literature review key findings.

2.9. Recovery from Energy Deficiency: The Potential for Rebound Hyperphagia

The first investigations to characterise the recovery from energetic deficit, were examined in case studies on ‘professional’ fasters (Benedict, 1907) and in a cohort during semi starvation (Benedict et al., 1919). Both of these studies highlighted a considerable ‘overshoot’ of BM beyond baseline values, as the participants entered a period of insatiable feeding. The landmark *Minnesota Starvation Experiment* by Keys et al. (1950) was the first to examine this process in detail. After a 24 week energy deficit period (where body mass was reduced by 25% via a 40% decrease in EI), the 32 participants were divided into four groups and completed an EI restricted recovery phase of 12 weeks on either an additional 400, 800, 1200 or 1600 kcal·day^{-1} with additional PRO and vitamin supplementation. Independent of which condition, in the following unrestricted recovery phase all participants exhibited exponential increases in EI causing considerable anthropometric changes in BM, which was elevated by over 10% above baseline, concomitant with substantial gains in FM. Alarmingly, one participant even consumed 11,500 kcal in one day and still expressed being hungry. Keys described this phenomenon as ‘post starvation obesity’, which is now characterised as rebound hyperphagia i.e. an increase in hunger and appetite (Dulloo et al., 2015).

Rebound hyperphagia has been also been exhibited in shorter time periods, with studies on US Army Rangers by Nindl et al. (1997) and Friedl et al. (2000) highlighting after eight weeks of energy deficit inducing 12% reductions in BM, there was a considerable rebound hyperphagic response in all participants leading to an increase in BM of 3-7% and fat overshoot by 40-60% above baseline. The psychological and physiological regulation of hyperphagia is complex and mediated by the same hypothalamic neuroendocrine axis as described in section 2.8.2. Additionally, Dulloo et al. (2015) hypothesises that rebound hyperphagia associated FM overshoot may be controlled by adipostat and proteinstat regulation, yet this still requires further proof of concept in humans. Given control of energetic metabolism during deficit and excess has been consistently debated for a number of years via ‘set point’ and ‘settling points’ theories on BM regulation (MacLean et al., 2011; Muller et al., 2010; Speakman et al., 2011), there must be a wider consideration that metabolic regulation can also be mediated via psychosocial (Polivy & Herman, 1985), modulation of AEE (Westerterp, 2013) and individual responses (Weyer et al., 2000) to variability in metabolomic (Sato et al., 2018; Strohacker et al., 2014) and genetic (Heinitz et al., 2018) factors. On this basis, gaining a clear understanding of the regulation of this phenomenon is still in its infancy.

To date no study has examined rebound hyperphagia in cohorts of combat sport athletes, yet it is recognised that this may be a potential issue given the culture of making weight practices and cycling (Burke et al., 2018a; Montani et al., 2015). Kasper et al. (2018) observed a rebound hyperphagic response in a professional MMA athlete post two weeks competitive period, where body mass was 4% above baseline, yet this timeframe was not long enough to observe substantial increases in FM. It has also been highlighted in a longitudinal study by Saarni et al. (2006) examining differences between weight cyclers and non-cyclers across 20 years, where BMI was considerably higher at middle age in those who participated in making weight sports, compared to other non-weight making athletes. Additionally, there are a number of associated fluctuations in blood pressure, HR, sympathetic activity, blood glucose, lipids and insulin, which can lead to a plethora of cardiometabolic health risks (Montani et al., 2015). Finally, the consistent cycling of BM can lead to a number of associated psychological issues, inclusive of body image dysmorphia, which may result in extreme depression and suicidal tendencies post competitive career (Hatton, 2013).

2.10. Summary

Following a comprehensive review of the literature, whilst there is a wide body of research examining the technical, tactical, anthropometrical, biomechanical, physiological and injury parameters of training and competition, there is a sparsity of investigations examining the BM loss practices of Taekwondo athletes. It is clear that Taekwondo has a unique making weight culture, which is in stark contrast to other combat sports in particular the grappling disciplines. However, whilst comparisons of making weight practices between differing age divisions have been conducted in other combat sports, this has never been explored in a group of Taekwondo athletes to examine the relationship in the differing amounts of OG and WT weight categories and their respective differences between the divisions as highlighted in Table 2.1. Further to this, no study has ever attempted to investigate the main influences on the engagement in making weight behaviours within this sport, to further elucidate stakeholder perceptions of current practice.

The methods of BM loss employed by Taekwondo athletes may have pronounced effects on psychological and physiological health and performance. Surprisingly to date, no study has ever investigated the magnitudes of BM loss when Taekwondo athletes are required to weigh in for their respective OG weight categories or examined this in tandem with the new re weigh in ruling. Despite a number of available body composition assessment measures, it appears the most commonly utilised method is $\sum_{SKf}$ and subsequent equations, yet the data produced from this technique has not been validated against criterion standards in this population. Additionally, research examining the measurement of AEE in Taekwondo activities is limited and utilising methodologies which are not applicable in the field, making it difficult for practitioners to assess LEA in this demographic. Finally, whilst only one study has highlighted the differences in both gradual and rapid approaches to making weight in Taekwondo, this has never been considered whilst investigating the potential for LEA leading to RED-S psychological and physiological health and performance consequences.

Therefore it is the intention of this thesis to undertake five separate studies within each of these areas, to further examine making weight practices in international standard Taekwondo athletes of differing sexes and age divisions, validate field based measures to examine EA status and offer alternate strategies to making weight employing scientifically considered methodologies.

CHAPTER 3.

Body Mass Loss and Ergogenic Dietary Supplement Practices in International Standard Taekwondo Athletes:

Effects of Sex and Age Division

3.1. Introduction

Taekwondo athletes lose BM in the belief that competing in a lower weight category, will give them competitive advantages over their opponents in both limb lever length and power to mass ratio (Bridge et al., 2014). Making weight practices and behaviours have been widely studied across a number of combat sports (see section 2.6) and it is essential to examine which BM loss regimen/s an athlete may be following, to further understand the impact this may have on overall health and performance. A number of investigations have examined the acute and chronic BM loss practises in Taekwondo athletes of independent age divisions and competitive levels (see section 2.6.6). Whilst these studies provide valuable information, it is important to compare the BM loss behaviours of both sexes and age divisions to assess if there are differences between practices, particularly given the reduction in weight categories in the older athlete groups. Additionally, it is also key to examine the disparity in behaviours and practices when considering BM loss requirements for the WT and OG weight categories as described in section 2.5. Generating further data from these enquiries may offer the information needed to formulate targeted making weight strategies and education to improve behaviours.

A number of studies have investigated ergogenic dietary supplement use in relation to making weight practices in combat sports (Crighton et al., 2016; Davis et al., 2001; de Assis et al., 2016; Halabchi et al., 2011; Kim et al., 2013; Kordi et al., 2011; Lakin et al., 1990). To date, only two studies have been conducted exploring this specifically in Taekwondo athletes (Bezci et al., 2018; Fleming & Costarelli, 2009), whereas a number of other studies have performed analyses as part of a group of sports (Braun et al., 2009; Heikkinen et al., 2011; Suzic Lazic et al., 2011). Examinations of doping histories/behaviours that may be linked to ergogenic dietary supplement use have been conducted in larger sporting sample groups (Barkoukis et al., 2011; Lazuras et al., 2010). Again, whilst these investigations provide useful insights, typical sample sizes have been minimal and do not examine these factors to elucidate a deeper level of analysis. A more focused understanding of the ergogenic dietary supplement use of Taekwondo athletes across sexes and age divisions could also afford the opportunity to examine potential differences, which may be linked to making weight behaviours.

The primary aim of this study was to examine the frequency, occurrence, magnitudes, methods and influences of acute and chronic BM loss practices, among international standard Taekwondo athletes of differing sexes, age divisions and OG/WT weight categories. A secondary aim was to concurrently analyse the ergogenic dietary supplement use, knowledge and doping histories of these athletes, which may be linked to the practices identified in the initial aim.

3.2. Methods

3.2.1. Participants

The study recruited both male and female participants who were competing in the 2015 British National Championships (n = 281). The inclusion criteria stipulated that participants were entered in an ‘elite’ category (minimum of 1st Dan black belt grade) and within one of the Cadet, Junior or Senior divisions, giving an age range of 12-35 years. All other competitors in the same categories, but not part of the elite division and those competing in the elite Child (<11 years of age) and Veteran categories (>35 years of age) were excluded from participation.

3.2.2. Procedures

The study was conducted in a cross sectional survey design utilising the Rapid Weight Loss Questionnaire (RWLQ), which has been administered in a number of previous combat sports studies and validated on a mixed sex population of >11 years of age (Artioli et al., 2010d). The survey questions were amended to reflect the participant demographic (see Appendix 1) and the study was approved by the Liverpool John Moores University research ethics committee.

At the event registration, a member of the research team informed all athletes who met the inclusion criteria about the study and requested their participation. Athletes who expressed interest were given an information sheet, which contained all of the necessary details to make contact should they have any queries about the questionnaire. Immediately post weigh in, those athletes who agreed to participate were guided to a designated data collection area (DCA) and after obtaining formal written consent (or parental/guardian consent in the instance of athletes below the age of 18 years), the participants were seated at an electronic data collection point (DCP) and requested to complete the questionnaire. The DCP consisted of a laptop station with screens to ensure privacy and confidentiality of individual participant responses. During data collection, members of the research team were present in the DCA for consultation on the questionnaire, should the participant need their assistance in explaining any of the information required. In any instances this was needed, those members of the research team who provided any necessary details ensured their responses and those of the participants, remained confidential at all times. Parents and guardians in the case of Junior and Cadet athletes under the age of 16 years were allowed to be present in the DCA during the data collection process at the participant's request, however, they were not permitted to be present with the participant at the DCP.

The questionnaire collated a number of sets of data including general information (sex, age, stature, current BM etc.), previous BM loss frequencies, magnitudes, methods and influences, including the Rapid Weight Loss Score (RWLS), which is a measure of the aggressiveness of these practices. Additionally, questions related to the use of both ergogenic dietary supplements and athletic doping histories, were also added to the questionnaire. Finally, in order to qualitatively assess both the psychological and physiological effects of BM loss, alongside the appropriate knowledge of both dose/use and potential adverse doping risks associated with ergogenic dietary supplements, participants were also requested to additionally comment on the questions pertaining to these factors (see Appendix 1).

3.2.3. Statistical Analysis

Descriptive statistics (i.e. mean, SD, mode, range and frequency) are provided for all variables where appropriate and data was explored for normality utilising box plots. A univariate two-way between subject's ANOVA was employed, to compare a number of variables relating to BM loss across the differing categories and sexes and the Bonferroni post hoc test was used for pairwise comparisons. Pearson's Chi Squared test was used, to compare percentage frequencies between divisions and sexes. All analyses were performed using SPSS version 24 (PASW, Chicago, Illinois, USA) and the alpha level was set at $p < 0.05$. All qualitative data were assessed via content analysis utilising data matrices, to elucidate the most common phrase responses (Miles et al., 2014).

3.3. Results

Overall, 106 athletes participated within the study, representing 37.7% of the targeted ‘elite’ divisions. This was divided between 79 males (74.5%), of which there were 21 Cadets (19.8%), 30 Juniors (28.3%), 28 Seniors (26.4%) and 27 females (25.5%), of which there were 4 Cadets (3.8%), 12 Juniors (11.3%) and 11 Seniors (10.4%). 100.0% of the athletes had competed at national championship level previously and 72.5% regularly competed internationally. Athletes reported competing 11 ± 2 times and winning medals 9 ± 2 times annually.

3.3.1. Participant Characteristics

Participant’s characteristics including training and competitive history are highlighted in Table 3.1. There was a main effect of age present between divisions ($p < 0.001$). The athletes’ stature differed between sexes ($p = 0.03$), where males were taller than females ($p = 0.03$), and also divisions ($p < 0.001$), where Seniors were taller than Juniors ($p = 0.03$) and Cadets ($p = 0.002$). There was an interaction for stature in all divisions ($p < 0.001$) where male Cadet to Junior divisions increased and female Cadet to Junior divisions decreased. The practicing age of divisions also differed ($p = 0.03$), with the Cadets starting earlier than Seniors ($p = 0.03$), however, this was not the case for competing age, despite a tendency for differences between Cadets in the male divisions and Seniors in the female divisions ($p = 0.05$).

Table 3.1. *Characteristics of Male/Female Cadet, Junior and Senior Taekwondo athletes.*
(All values are Mean ± SD and include the Mode and Range.)

SEX	**MALE** **n = 79**			**FEMALE** **n = 27**		
DIVISION	**Cadet** **n = 21**	**Junior** **n = 30**	**Senior** **n = 28**	**Cadet** **n = 4**	**Junior** **n = 12**	**Senior** **N = 11**
Age (years) [a]	13 ± 1 14 (11-14)	16 ± 1 16 (15-18)	22 ± 4 19 (17-32)	12 ± 1 - (11-14)	16 ± 1 15 (14-17)	25 ± 6 28 (16-38)
Stature (cm) [a b c]	163 ± 13 168 (134-190)	176 ± 9 170 (160-196)	181 ± 8 180 (158-196)	167 ± 18 - (150-190)	164 ± 7 166 (153-177)	172 ± 7 178 (160-185)
Practicing Age (years) [d]	7 ± 2 5 (3-11)	9 ± 3 6 (4-14)	9 ± 5 5 (4-21)	6 ± 1 6 (4-7)	9 ± 3 7 (4-15)	10 ± 4 10 (4-16)
Competing Age (years)	9 ± 2 8 (4-13)	11 ± 3 9 (6-16)	11 ± 4 9 (5-21)	10 ± 3 12 (7-12)	10 ± 3 8 (7-15)	13 ± 5 7 (6-22)

[a] *significant main effect of all divisions ($P < 0.05$)*
[b] *significant main effect of sex ($P < 0.05$)*
[c] *significant interaction males vs. females/cadet vs. junior ($P < 0.05$)*
[d] *significant main effect cadet vs. senior divisions ($P < 0.05$)*

3.3.2. Body Mass Loss Frequencies and Habits

Table 3.2. highlights the BM loss frequencies and habits of the participants and is inclusive of heavyweight athletes who reported BM loss in their responses. Overall 79.2% of participants reported losing BM for competition with no differences ($p = 0.15$) between combined male (75.9%) and female (88.9%) divisions. However, there was a difference present between those reporting BM losses in the male age divisions ($p = 0.01$), but not in the female age divisions ($p = 0.63$) and also an increasing occurrence of BM loss between sex combined Cadet (60.0%), Junior (83.3%) and Senior (87.2%) divisions, respectively ($p = 0.02$). There was a main effect between divisions in usual BM lost in kg ($p < 0.001$), where Seniors lost more BM than Cadets ($p < 0.001$), as did Juniors ($p = 0.03$). This main effect persisted when BM loss was calculated relatively ($p = 0.002$), where Seniors ($p < 0.001$) and Juniors ($p = 0.02$) lost more than Cadets. For Juniors and Seniors, there were no differences in the usual BM loss between Olympic divisions ($p = 0.35$), between sex ($p = 0.59$), or when this was expressed relatively between division ($p = 0.61$) and sex ($p = 0.83$). There was a main effect present for most

BM lost in kg (*p* = 0.001), where Seniors lost more BM than both Juniors (*p* = 0.04) and Cadets (*p* = 0.002). This main effect was also continued when most BM was calculated relatively (*p* = 0.03), however, this exhibited differing results to absolute values, where Seniors only lost more BM than Cadets (*p* = 0.03). Usual BM loss period also displayed a similar main effect (*p* = 0.004), where Seniors lost BM over a longer period than Cadets (*p* = 0.04) and this was also similar in the usual BM regain after a 7 day period (*p* = 0.03), where Seniors regained more BM than Cadets (*p* = 0.03). There were no differences in the number of annual BM loss attempts between sexes (*p* = 0.62), or divisions (*p* = 0.16). However, there was main effect between the age which participants began to lose BM (*p* = 0.001), where yet again Seniors began to lose BM at a later age than both Juniors (*p* = 0.001) and Cadets (*p* = 0.001).

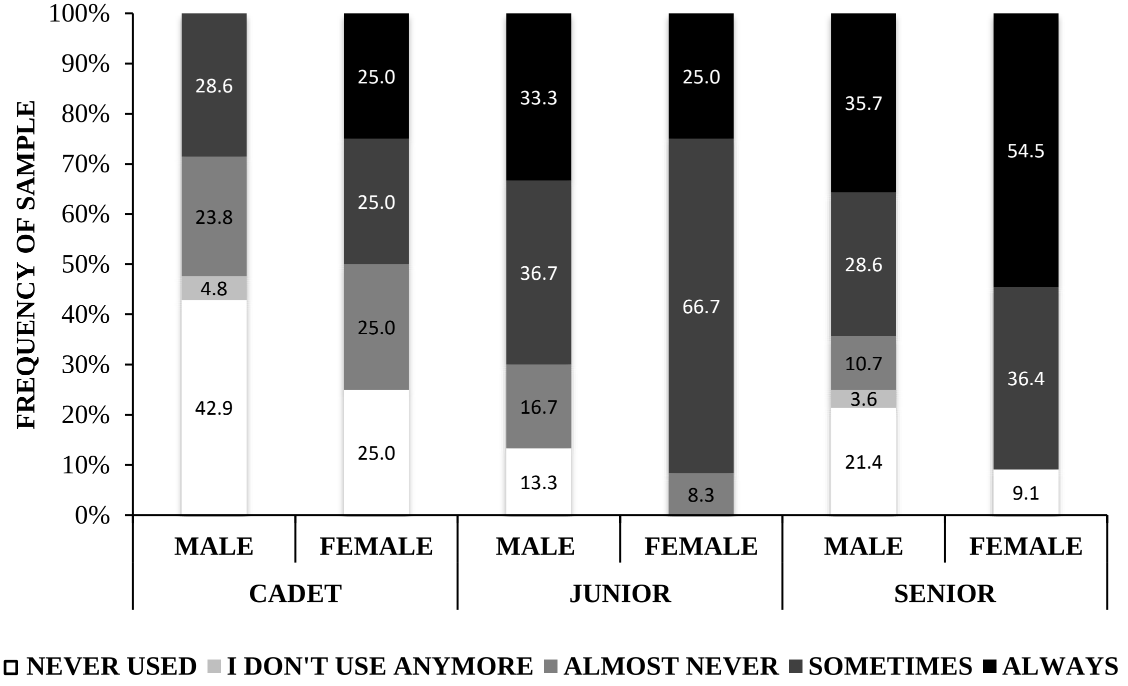
3.3.3. Body Mass Loss Methods and Influences

Frequency analysis of BM loss methods and influences are shown in Figures 3.1 and 3.2, respectively. Responses can be seen in the legend below each graph and higher frequency responses are shown in darker bars. There was an increasing trend in occurrence, across the Cadet, Junior and Senior divisions for the use of energy restriction as a method of BM loss, in the forms of gradual dieting (Fig. 3.1 A.), skipping meals (Fig. 3.1 B.) and fasting (Fig. 3.1 C.). Dehydrative methods of BM loss in the forms of restricting fluids (Fig. 3.1 D.), use of saunas/steam rooms (Fig. 3.1 E.) and sweat suits (Fig. 3.1 F.) also followed the same trend. An increase in the amount of exercise to elevate energetic expenditure was widely prevalent across all categories (Fig. 3.1 G.), whereas the use of hot/salt baths, as means of passive dehydration for BM loss was not as frequent across all categories (Fig. 3.1 H.).

Table 3.2. *BM loss frequencies and habits of Male/Female Cadet, Junior and Senior Taekwondo athletes.*
(All values are Mean ± SD and include the Mode and Range.)

SEX (incl. percentage of participants who reduced body mass)	**MALE n =60 (75.9%)**			**FEMALE n = 24 (88.9%)**		
DIVISION (incl. percentage of participants who reduced body mass) [a][b]	**Cadet n = 11 (52.4%)**	**Junior n = 25 (83.3%)**	**Senior n = 24 (85.7%)**	**Cadet n = 4 (100%)**	**Junior n = 10 (83.3%)**	**Senior N = 10 (90.9%)**
USUAL body mass lost (Kg) WT Division [c][d]	1.0 ± 0.6 1.0 (0.0-2.0)	1.9 ± 1.3 1.0 (0.5-5.0)	3.2 ± 2.0 2.0 (0.0-8.0)	0.4 ± 0.4 - (0.0-1.0)	2.1 ± 1.0 2.0 (1.0-4.0)	2.3 ± 0.9 2.0 (1.0-4.0)
USUAL relative body mass lost (%) WT Division [c][d]	2.1 ± 1.0 - (0.0-3.7)	3.2 ± 2.1 - (1.0-8.6)	4.5 ± 2.8 - (0.0-10.3)	0.8 ± 0.8 - (0.0-1.7)	3.8 ± 2.0 - (1.4-7.0)	4.0 ± 1.6 - (2.1-7.0)
USUAL body mass lost (Kg) OLYMPIC Division	N/A	2.7 ± 2.1 3.0 (0.4-8.8)	4.7 ± 3.0 6.0 (0.5-11.9)	N/A	3.6 ± 2.7 - (0.6-9.0)	3.0 ± 2.5 2.0 (0.2-9.0)
USUAL relative body mass lost (%) OLYMPIC Division	N/A	4.5 ± 3.4 - (0.6-14.0)	6.8 ± 4.2 - (0.9-16.4)	N/A	6.4 ± 4.8 - (1.4-16.4)	5.4 ± 5.2 - (0.4-18.4)
MOST body mass lost (Kg) [d][e]	2.1 ± 2.2 1.0 (0.1-8.0)	3.2 ± 2.1 3.0 (1.0-9.8)	5.7 ± 3.2 7.0 (2.0-15.0)	1.9 ± 1.8 - (0.4-4.3)	3.6 ± 2.0 6.0 (0.6-10.0)	4.5 ± 2.4 4.0 (1.0-9.0)
MOST relative body mass lost (%) [d]	3.9 ± 2.8 - (0.2-9.4)	5.3 ± 3.0 - (1.7-15.9)	8.0 ± 4.4 - (2.8-18.8)	4.2 ± 4.3 - (0.8-10.5)	6.8 ± 4.7 - (1.4-17.6)	7.0 ± 3.2 - (2.1-19.3)
USUAL body mass loss period (days) [d]	6 ± 5 5 (0-14)	12 ± 8 14 (3-30)	18 ± 15 14 (0-56)	9 ± 7 - (2-18)	15 ± 6 14 (3-21)	23 ± 17 14 (1-60)
USUAL body mass regain (Kg/Week) [d]	1.3 ± 1.0 1.0 (0.5-4.0)	1.8 ± 1.1 2.0 (0.0-4.0)	2.6 ± 1.9 2.0 (0.0-8.0)	0.9 ± 0.7 - (0.4-2.0)	1.8 ± 1.0 1.0 (1.0-4.0)	2.2 ± 1.2 2.0 (1.0-4.0)
ANNUAL body mass loss attempts	11 ± 1 10 (10-13)	11 ± 2 10 (8-20)	12 ± 2 10 (8-16)	11 ± 1 - (10-12)	11 ± 1 10 (9-12)	12 ± 1 13 (10-14)
AGE began to lose body mass (Years) [d][e]	12 ± 1 12 (10-14)	14 ± 2 15 (11-18)	16 ± 3 14 (10-22)	11 ± 2 - (8-13)	14 ± 1 14 (11-16)	17 ± 4 13 (12-23)

[a] *significant main effect male divisions ($P < 0.05$)*
[b] *significant main effect all sex combined divisions ($P < 0.05$)*
[c] *significant main effect cadet vs. junior divisions ($P < 0.05$)*
[d] *significant main effect cadet vs. senior divisions ($P < 0.05$)*
[e] *significant main effect junior vs. senior divisions ($P < 0.05$)*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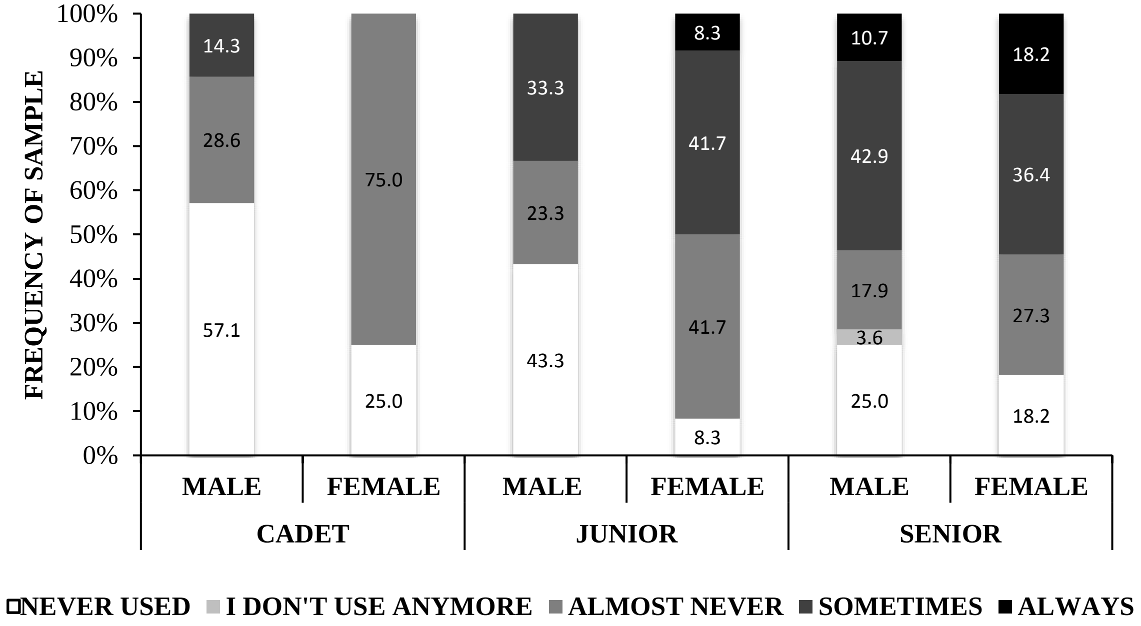
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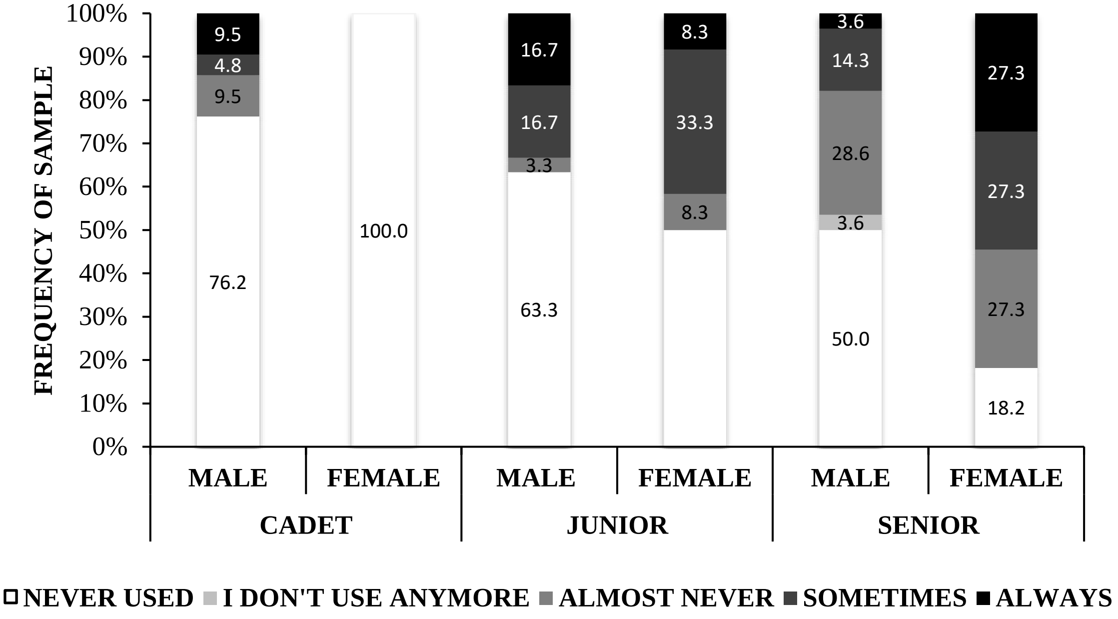
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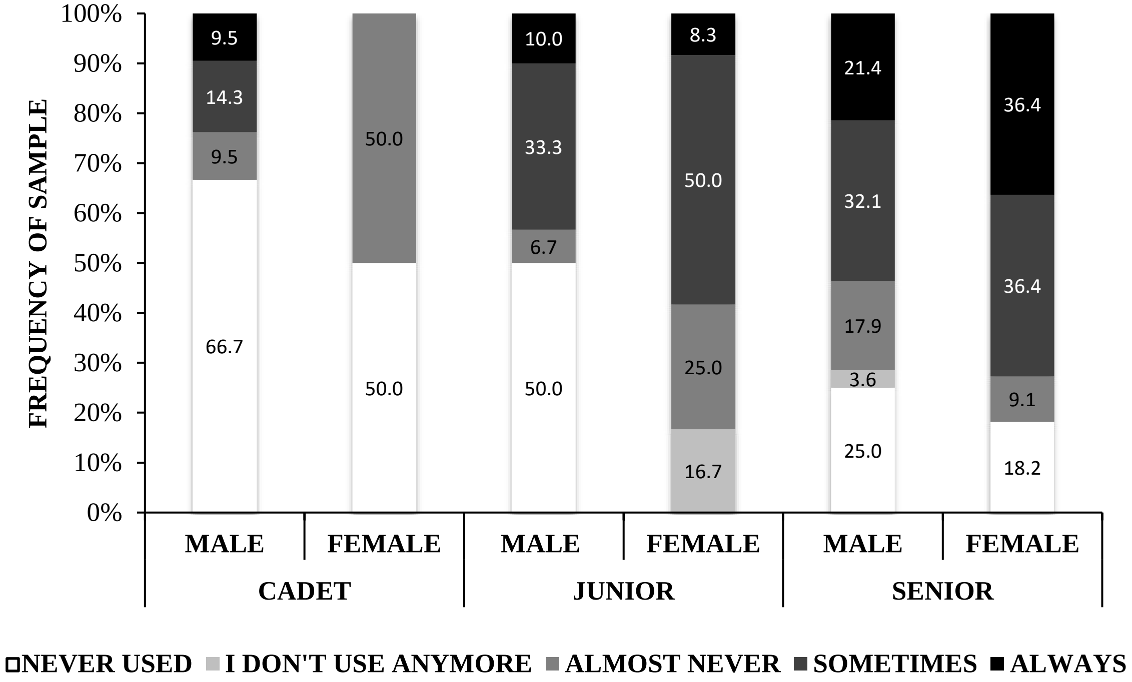
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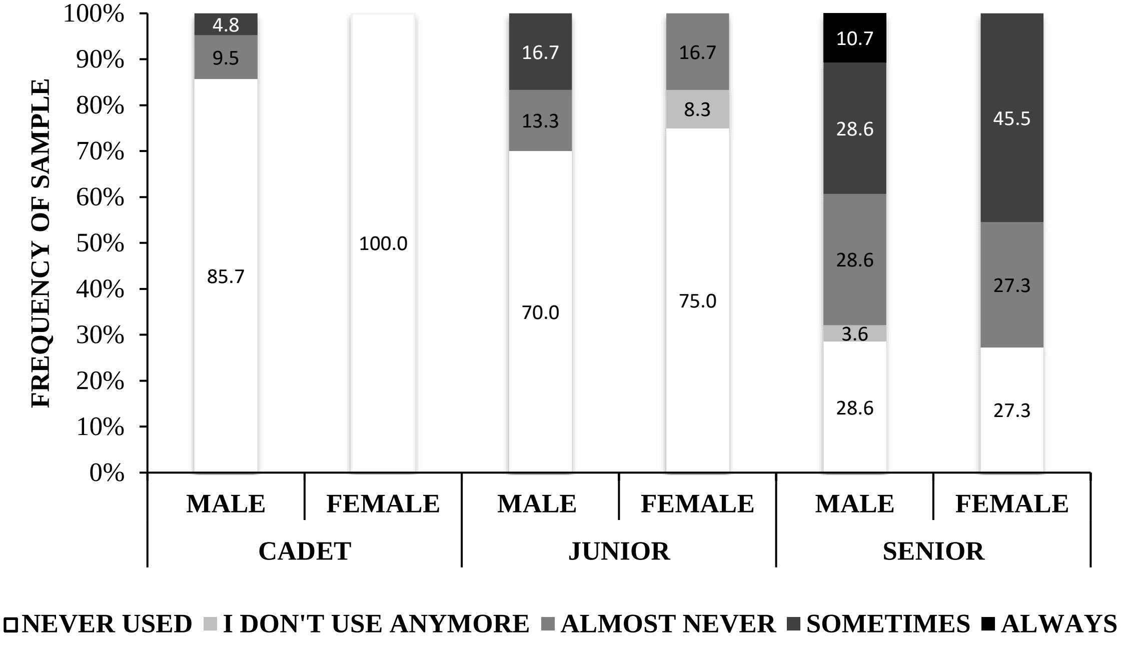
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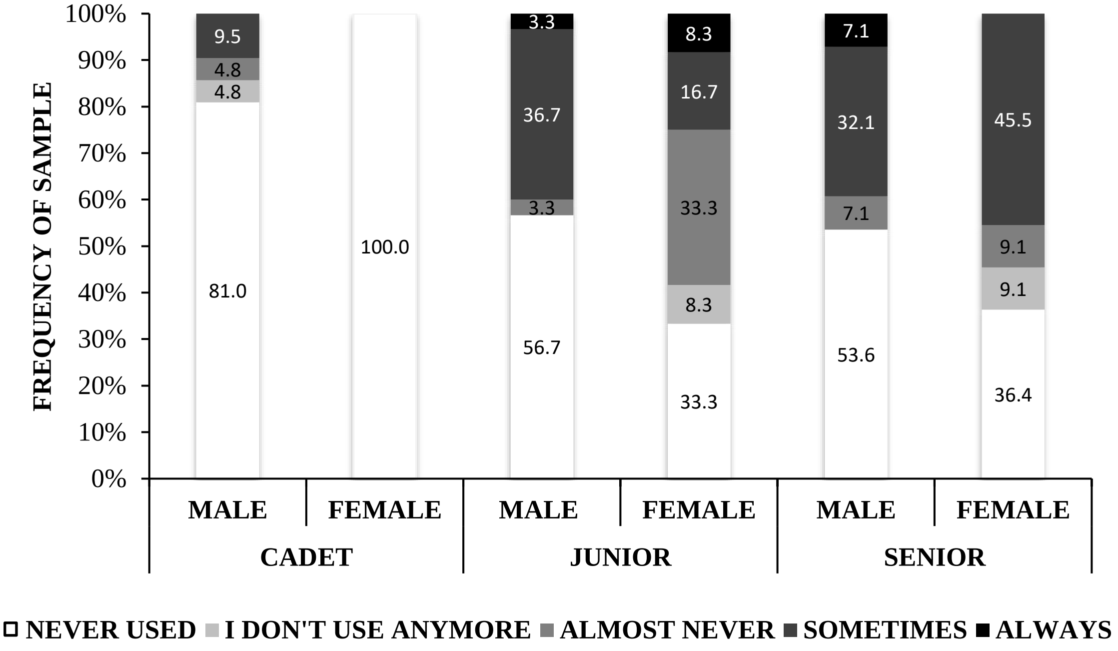
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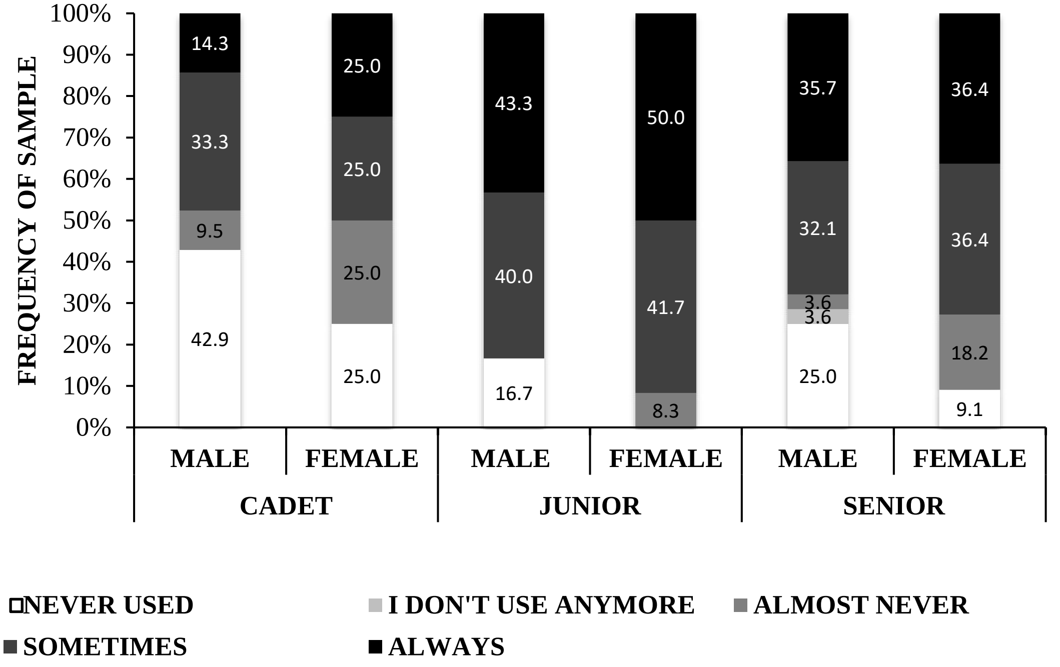

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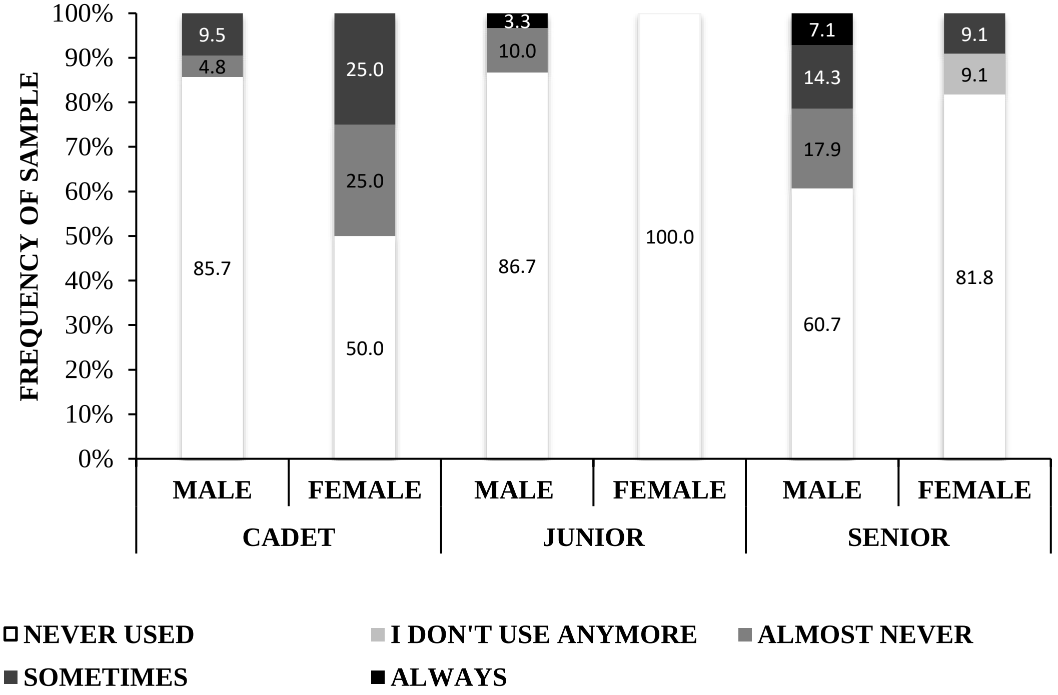

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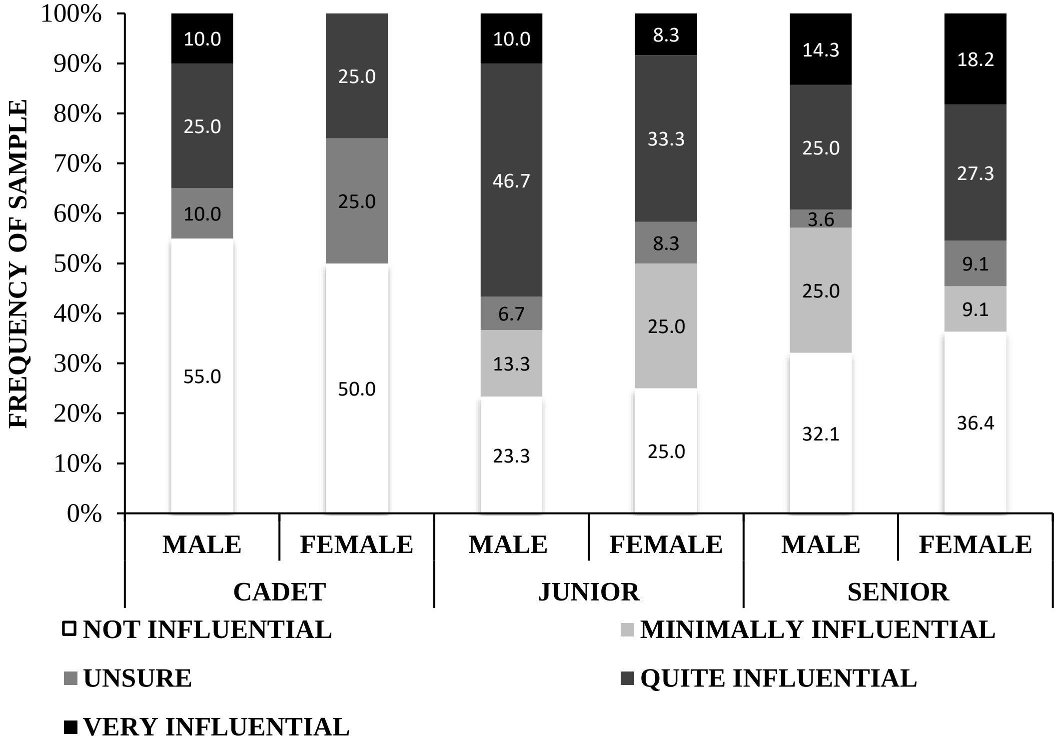
Figure 3.1: *Frequency analysis of BM loss methods (A. Gradual Dieting; B. Skipping Meals; C .Fasting; D. Restricting Fluids; E. Sauna/Steam Room; F. Sweat Suits; G. Increasing Exercise; H. Hot/Salt Bath) in Male/Female Cadet, Junior and Senior international standard Taekwondo athletes.*

Other training colleagues (Fig. 3.2 A.) and competitors (Fig. 3.2 B.), had a large amount of influence on the engagement of BM loss across all divisions. This was also demonstrated for coach/physical trainers (Fig. 3.2 C.), who had the most influence across all divisions and parents (Fig. 3.2 D.), who had a larger influence on Cadet and Junior divisions. Professional personnel in the form of physicians/doctors (Fig. 3.2 E.), physiotherapists (Fig. 3.2 F.) and nutritionists (Fig. 3.2 G.) had a limited influence on all divisions, with the use of online resources (Fig. 3.2 H.) having a minimal influence on all divisions overall.



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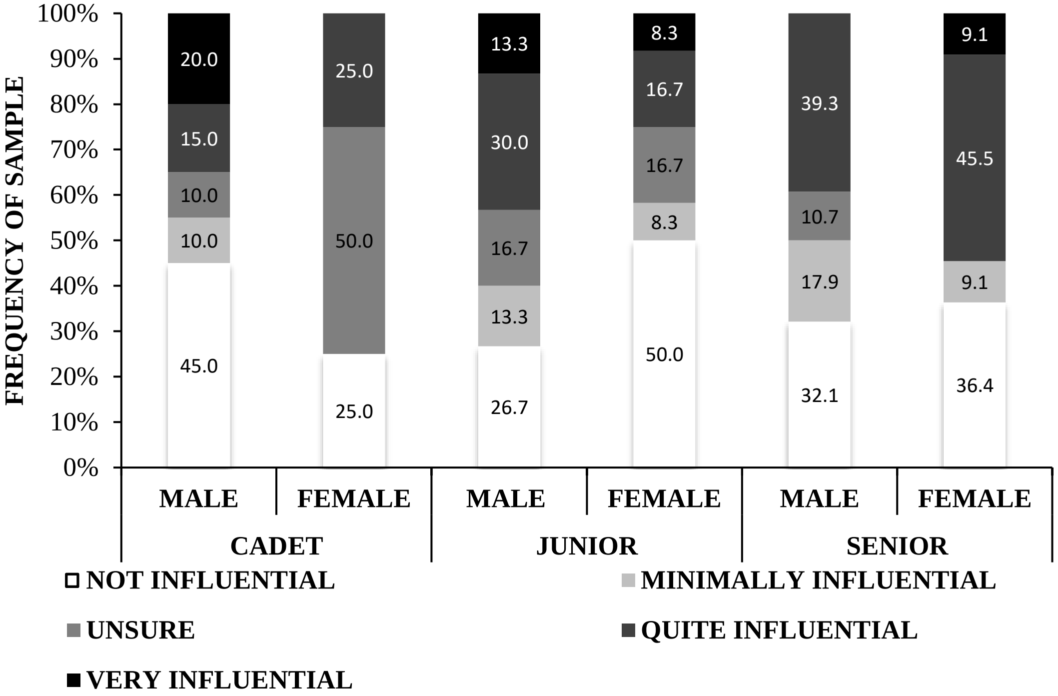
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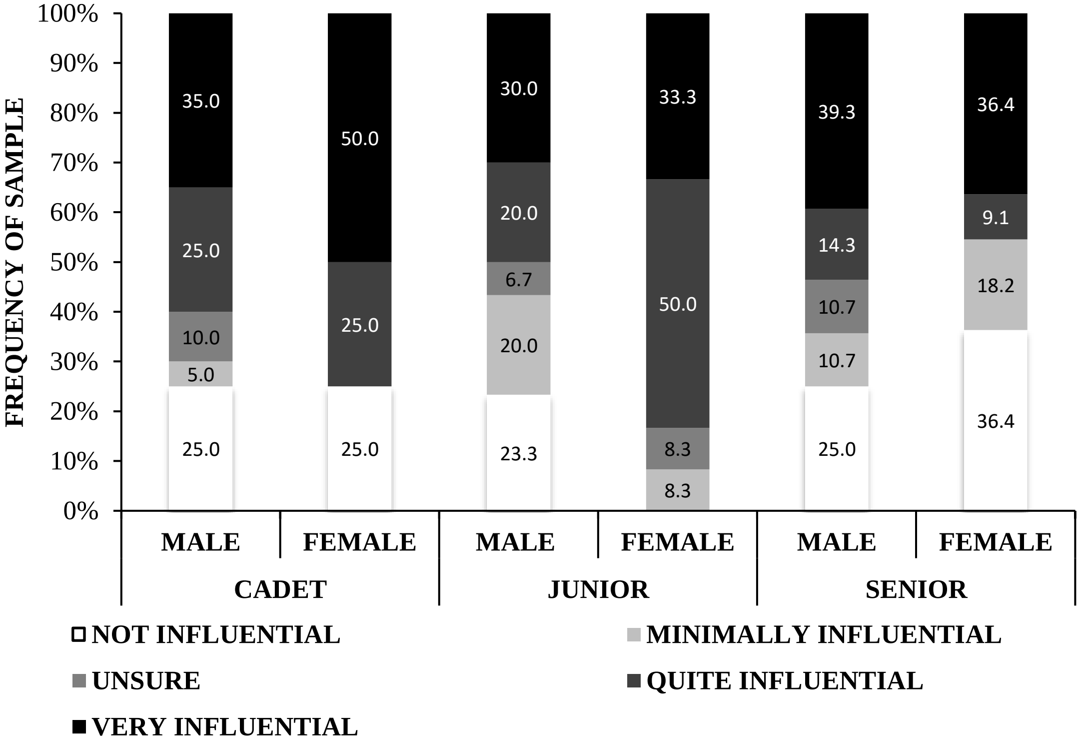
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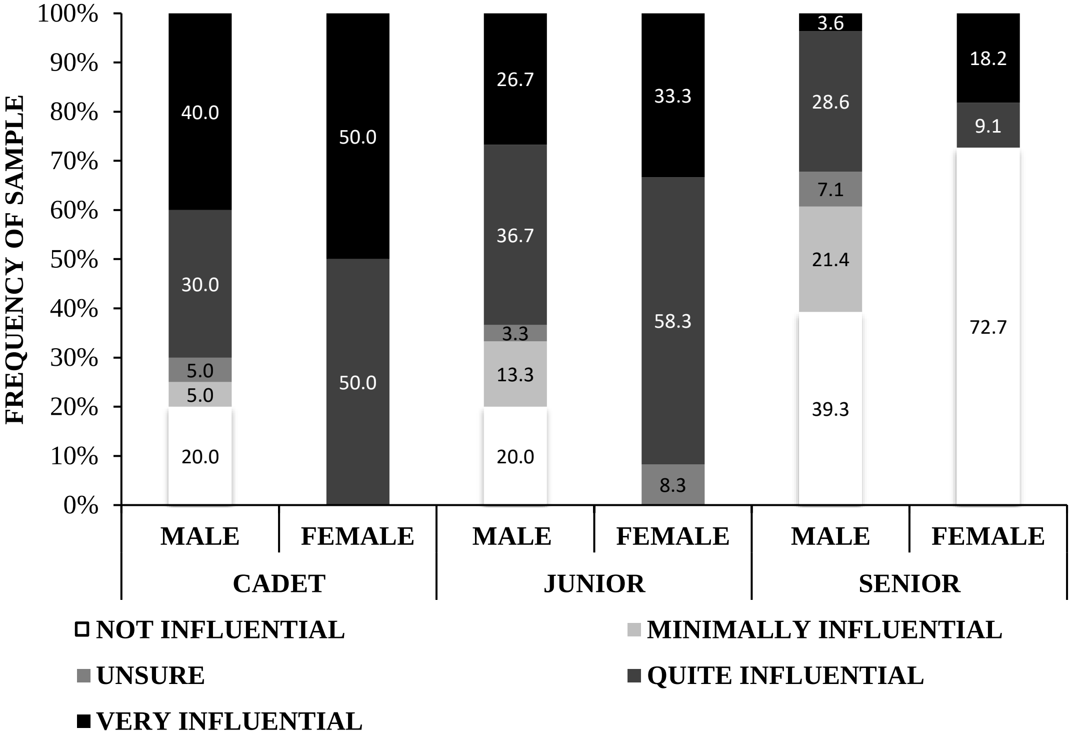
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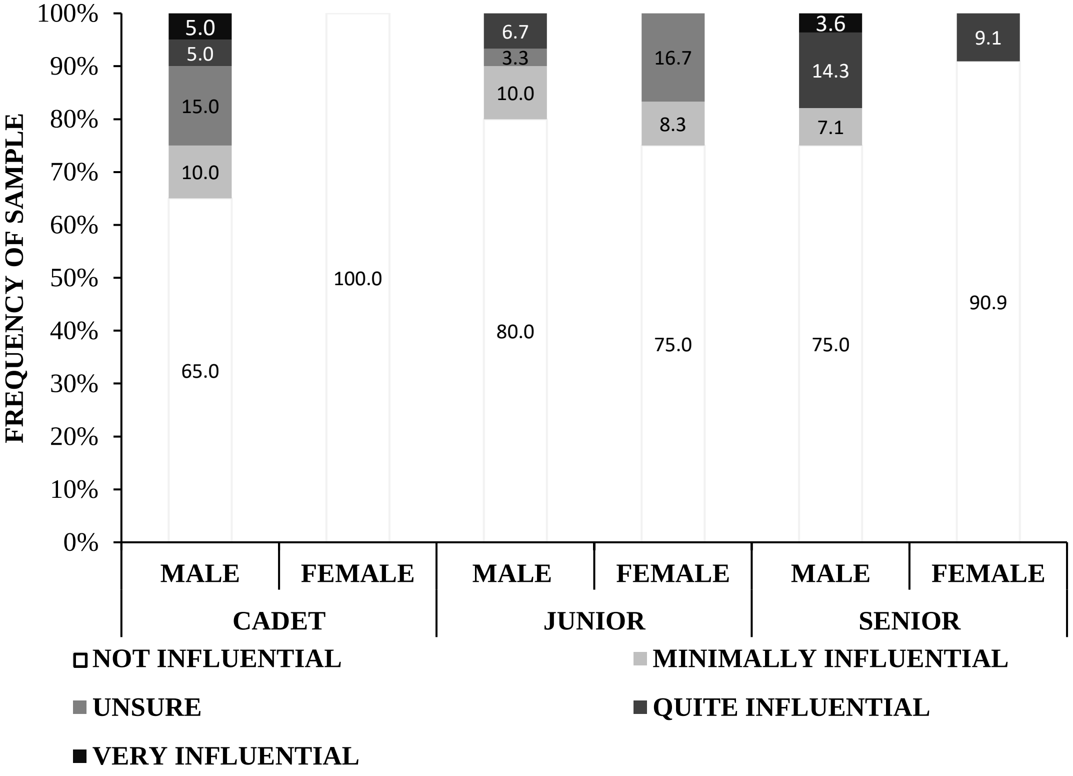
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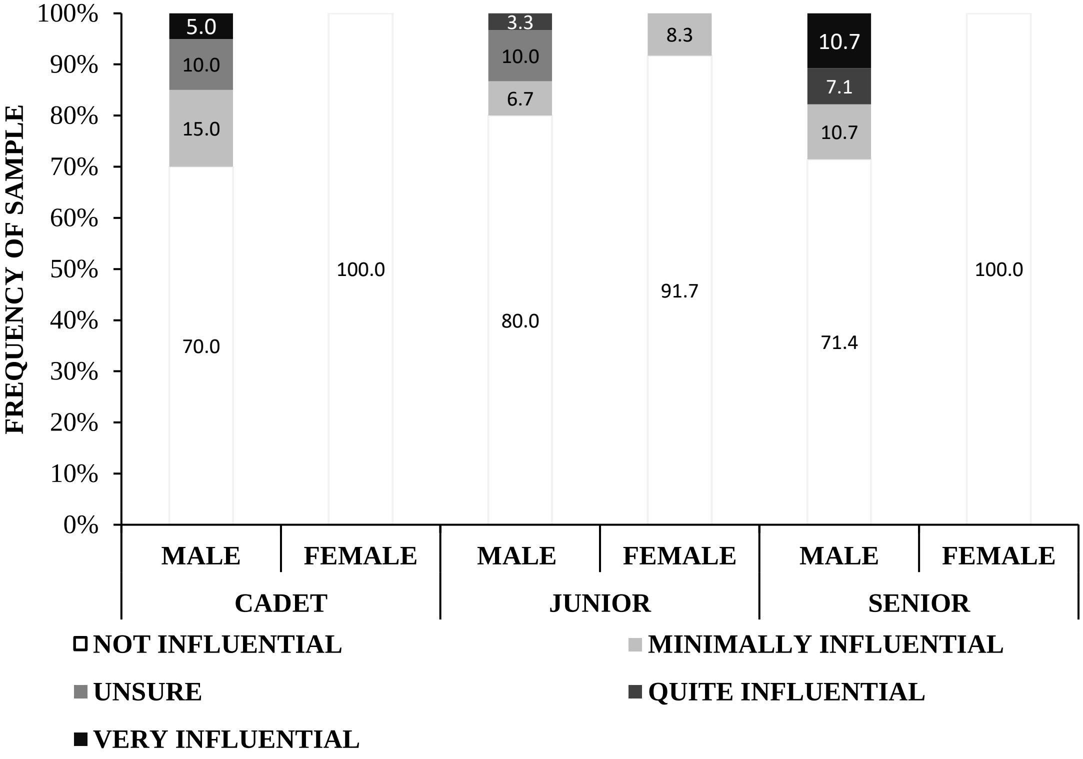
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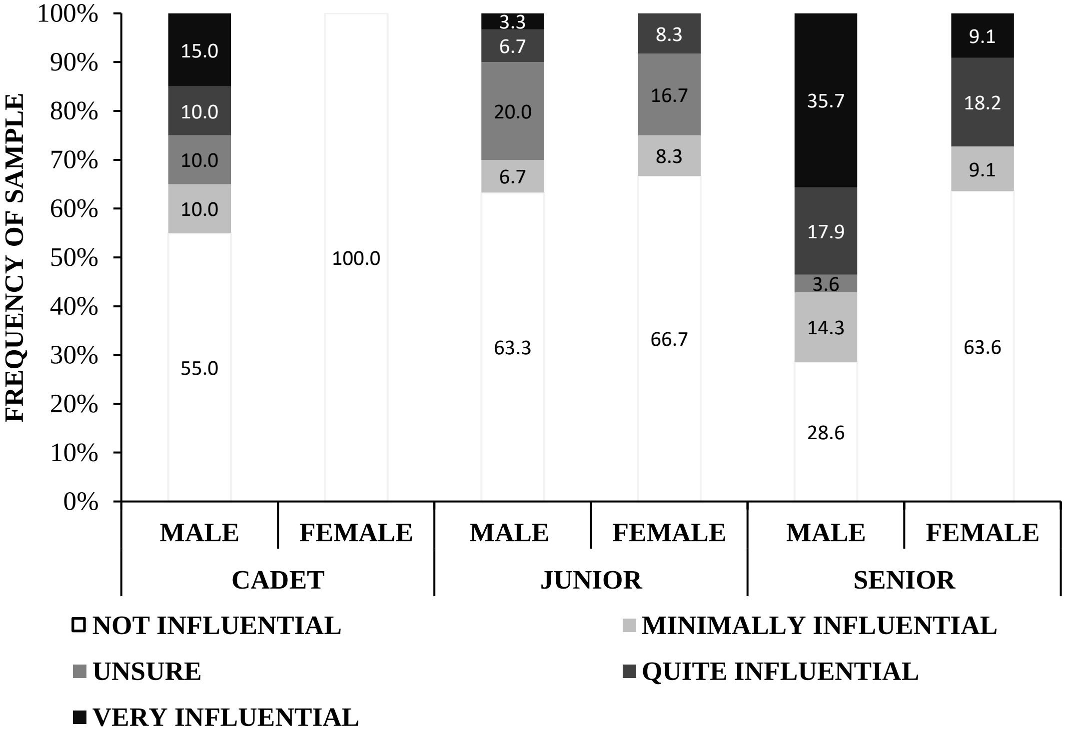
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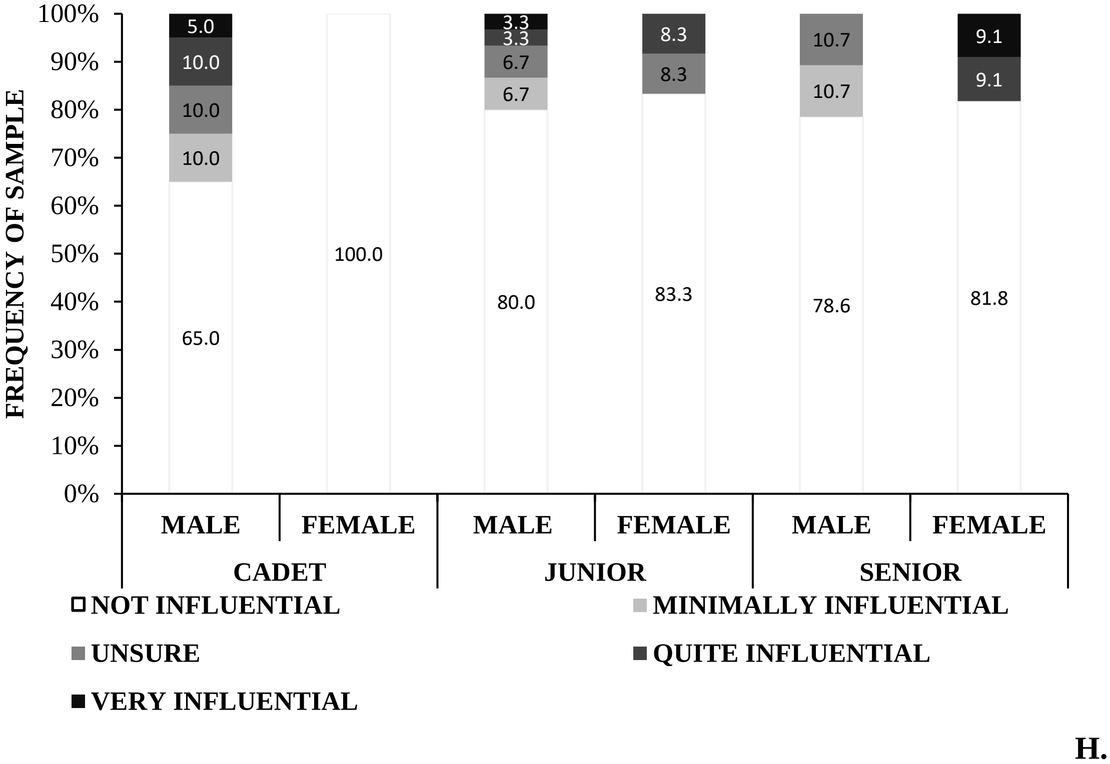
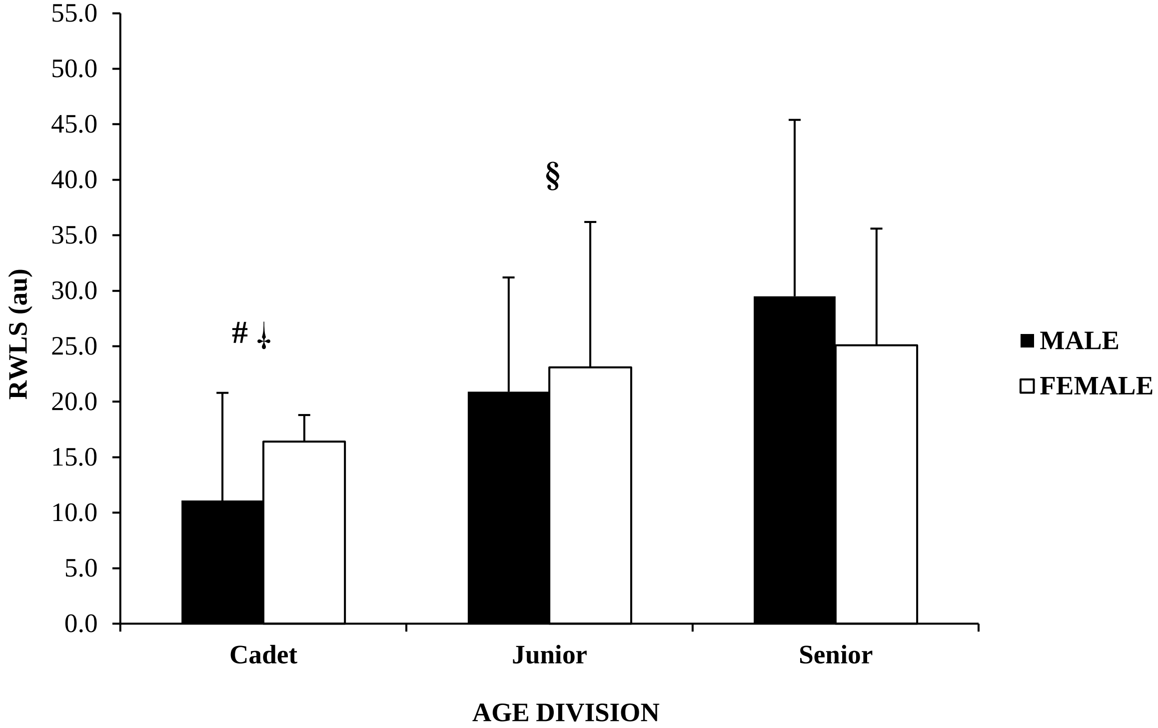


Figure 3.2: *Frequency analysis of main influences on BM loss practices (A. Training Colleague; B. Another Competitor; C .Coach/Physical Trainer; D. Parents; E. Physician/Doctor; F. Physiotherapist; G. Nutritionist; H. Online Resources) in Male/Female Cadet, Junior and Senior international standard Taekwondo athletes.*

3.3.4. Rapid Weight Loss Score Between Divisions and Sexes

The RWLS between sexes and divisions is presented in Figure 3.3. There were no differences between the sexes ($p = 0.71$), yet a main effect for division ($p = 0.003$), where the Cadet division score was lower than the Junior division ($P = 0.007$) and Senior division ($p < 0.001$) scores and the Junior division score was lower than the Senior division ($p = 0.04$) score.



[#] significant main effect sex combined cadet vs. junior divisions ($P < 0.05$)
[ⱡ] significant main effect sex combined cadet vs. senior divisions ($P < 0.05$)
[§] significant main effect sex combined junior vs. senior divisions ($P < 0.05$)

Figure 3.3. *RWLS of Male/Female Cadet, Junior and Senior international standard Taekwondo athletes.*
(All values are Mean ± SD)

3.3.5. Ergogenic Dietary Supplement Use and Doping Test Histories

Table 3.3. highlights the ergogenic dietary supplement use of athletes in both sexes and divisions. Out of 50 ergogenic dietary supplements, only 20 were identified as used by at least one of the divisions across the participant sample. Overall there were no main differences between sexes other than for green tea (p = 0.09), where use was predominantly higher in females. Meal replacement supplements showed a tendency for differences (p = 0.05), where use was higher in females, as did post work out products (p = 0.05), where use was higher in males. There were no key differences between both male/female and sex combined divisions for the use of β-alanine, caffeine, casein, fish oils, glutamine, glucosamine, sodium bicarbonate, soy protein, tart cherry juice, and

vitamins. There were highlighted differences in the male divisions for the use of creatine ($p = 0.04$), energy gels ($p = 0.02$), energy bars ($p = 0.07$) and a trend for significance in energy drinks ($p = 0.05$). For all the aforementioned ergogenic dietary supplements there were no differences between the female divisions, yet there were between sex combined divisions for creatine ($p = 0.02$), energy gels ($p = 0.003$), energy bars ($p = 0.02$), but not energy drinks ($p = 0.13$). There was no use of pre or post workout products in the female divisions, yet there was a difference in use between pre ($p = 0.02$) and post ($p < 0.001$) workout products in male divisions, where this only occurred in the Senior division. There was a difference in the use of whey protein across the male divisions ($p = 0.001$) and female divisions ($p = 0.01$) and sex combined divisions ($p = 0.001$), where there was overall increased use in the Senior divisions. Additionally, there were differences in sex combined divisions for the use of both electrolytes ($p = 0.01$) and meal replacement supplements ($p = 0.02$). There was no difference between combined male and female doping test histories ($p = 0.38$), however, there was between male ($p = 0.08$) and female ($p = 0.03$) divisions and an increase in sex combined Cadet (0.0%), Junior (6.7%) and Senior (23.1%) doping test histories, respectively ($p = 0.004$).

Table 3.3. *Frequency analysis of ergogenic dietary supplement use in Male/Female Cadet, Junior and Senior Taekwondo athletes. (All values report the percentage of use.)*

SEX	**MALE n = 79**			**FEMALE n = 27**		
DIVISION	**Cadet n = 21**	**Junior n = 30**	**Senior n = 28**	**Cadet n = 4**	**Junior n = 12**	**Senior N = 11**
β-Alanine (Beta- alanine)	0.0%	**3.3%**	**14.3%**	0.0%	**8.3%**	**9.1%**
Caffeine (including coffee)	**9.5%**	**23.3%**	**35.7%**	**25.0%**	**25.0%**	**36.5%**
Casein Protein	**4.8%**	**3.3%**	**7.1%**	0.0%	0.0%	0.0%
Creatine (all forms) [b d]	0.0%	**3.3%**	**17.9%**	0.0%	0.0%	**9.1%**
Electrolytes (Drinks &/or tablets) [d]	**28.6%**	**36.7%**	**60.7%**	**50.0%**	**8.3%**	**54.5%**
Energy Gels [b d]	**4.8%**	**10.0%**	**32.1%**	0.0%	0.0%	**27.3%**
Energy Bars [b d]	**9.5%**	**26.7%**	**39.3%**	0.0%	**8.3%**	**36.4%**
Energy Drinks (Still & carbonated)	**23.8%**	**56.7%**	**53.6%**	**50.0%**	**16.7%**	**54.5%**
Fish Oils (Cod Liver, Omega 3/6/9, Krill, etc.)	**4.8%**	**20.0%**	**28.6%**	**25.0%**	**8.3%**	**18.2%**
Glutamine	0.0%	**3.3%**	**7.1%**	0.0%	0.0%	**9.1%**
Glucosamine	0.0%	0.0%	**3.6%**	0.0%	0.0%	**9.1%**
Green Tea (Including extract) [a]	**4.8%**	**13.3%**	**21.4%**	**50.0%**	**16.7%**	**54.5%**
Meal Replacement Supplements (Bars/powders) [d]	0.0%	0.0%	**10.7%**	0.0%	**8.3%**	**27.3%**
Pre work out products[b d]	0.0%	0.0%	**14.3%**	0.0%	0.0%	0.0%
Post work out products [b d]	0.0%	0.0%	**35.7%**	0.0%	0.0%	0.0%
Sodium Bicarbonate	0.0%	0.0%	**3.6%**	0.0%	0.0%	**8.3%**
Soy Protein	**4.8%**	0.0%	**7.1%**	0.0%	0.0%	0.0%
Tart Cherry Juice	0.0%	**3.3%**	**3.6%**	0.0%	0.0%	0.0%
Whey Protein (All forms) [b c d]	**9.5%**	**3.3%**	**46.4%**	0.0%	0.0%	**45.5%**
Vitamins (Multi and/or individual vitamins)	**14.3%**	**26.7%**	**32.1%**	**50.0%**	**8.3%**	**45.5%**

[a] *significant difference sex* ($p < 0.05$)

[b] *significant difference male divisions* ($p < 0.05$)

[c] *significant difference female divisions* ($p < 0.05$)

[d] *significant difference all sex combined divisions* ($p < 0.05$)

3.4. Discussion

The main aim of this study was to examine the frequency, occurrence, magnitudes, methods and influences of acute and chronic BM loss practices and ergogenic dietary supplement use/knowledge, among international standard Taekwondo athletes of differing sexes, age divisions and OG/WT weight categories. This is the first BM loss survey conducted in any combat sport, immediately post competition weigh in. The importance of this factor, is that in contrast to many of the other surveys reported in the literature, which may have been completed during the in/off periods of a competitive season (or even during a competition period), the information presented immediately captures not only quantitative data, but the perceptions and attitudes of the athletes during the most pivotal point in their individual BM loss processes.

The results of this study agree with a number of other investigations described in section 2.6, which indicate there are no differences between the frequency, occurrences, magnitudes, methods and influences of BM loss in combat sports between sexes. Many other studies have compared the differences between varying combat sport disciplines (Barley et al., 2017; Brito et al., 2012; Reale et al., 2017c), athletes of differing competitive levels (da Silva Santos et al., 2016; Steen & Brownell, 1990) and also individual age categories including youth and senior athletes. However, this is the first study to compare the differences between age divisions in international standard Taekwondo athletes and only the third study to do so in combat sports (Alderman et al., 2004; Escobar-Molina et al., 2015). As the data demonstrates, there is a progressive increase in the occurrence of both usual and most BM lost from Cadet to Junior and Senior divisions and this pattern also shows a similar trend for the amount of BM regain within a 7 day period. Intriguingly, the amount of time engaged in BM loss, seems dependent on how much is lost, where Seniors lose more BM over a longer time period and contrastingly this trend decreases in both the Junior and Cadet divisions. All divisions engage in the same amount of annual mean BM loss attempts and the age at which each division began to lose BM also increases throughout the divisions. Other studies have reported a mean age of 14 ± 2.1 years old (Franchini et al., 2012), which agrees with the data from this study at 15 ± 4 years old when examined collectively. The data from this investigation also includes heavyweight athletes, who are often excluded from the analysis of many other BM loss survey studies (Artioli et al., 2010b; da Silva Santos et al., 2016). By including data from this sub category BM loss prevalence is exhibited at 79.2% of the participant sample, however upon exclusion, this is reduced to 71.7%. After discussion with many of the heavyweight athletes about why they conducted BM loss, despite not needing too in order to meet their category limit, many of the responses included the need to '*feel lighter*' so they could '*move quicker*'.

Alarmingly, as the occurrence of BM loss increases throughout the age divisions, so does the magnitude. A high proportion of athletes report losing >5% of their BM in order to compete and despite this study being conducted prior to its instatement, this is in direct contravention of the global federation (WT) ruling, where athletes who are randomly selected to re-weigh in the morning of competition are disqualified if their BM is above 5% of their weight category limit (World Taekwondo, 2018a). For most BM ever lost, 40.0% (45.5% in males/25.0% in females) of Cadet, 45.7% (40.0% in males/60.0% in females) of Junior and 73.5% (75.0% in males/70.0% in females) of Senior division athletes have lost over this amount at some point in their competitive career. There was no description of usual BM losses >5% in the Cadet divisions, however, this was reported in the WT Junior categories where 22.9% of athletes (20.0% in males/30.0% in females) lost over this amount with the highest range from 7.0-8.6%. In the Olympic Junior categories, this magnitude is exacerbated even further to 40.0% of athletes (50.0% in males/44.4% in females) with the highest range of loss from 14.0-16.4%. For WT Senior categories, over 32.3% (37.5% in males/22.2% in females) of athletes also lost >5% of BM, with the highest range of loss at 7.0-10.3% and in the Olympic Senior categories, again this magnitude was again inflated to 48.4% (61.9% in males/44.4% in females) of athletes, with the highest ranges of loss being 16.4-18.4%, respectively. These magnitudes are considerably higher than previously categorised in the literature, with ranges exhibiting similarities to other combat sports such as MMA (Barley et al., 2017; Crighton et al., 2016), where this is not uncommon practice (see section 2.6.3).

When examining the methods utilised to achieve BM loss, energy/fluid restriction and increased energetic expenditure are the most common practices across both sexes and divisions in agreement with other studies as highlighted in section 2.6.6. Another trend can also be observed, where the increased frequency in the employment of these methods is linked to the amount of BM loss between the divisions, given use is much higher in Seniors compared to Juniors and Cadets. The questionnaire also gathered information on other more dangerous methods of BM loss, which are not included in Figure 3.1. due to their limited frequency of use. Many of these other extreme methods were almost exclusively used in the Senior division and included the use of fat burners, diuretics, laxatives and enemas. The use of both spitting and vomiting, were employed in both the Junior and Senior divisions and interestingly the use of water loading, which is a common BM reduction technique amongst MMA athletes (see section 2.6.3) showed a limited prevalence in all of the male divisions. The content analysis of qualitative responses indicating use of these methods, highlighted common themes between both sexes and all of the divisions. Many athletes reported feeling '*hungry*', '*tired*' and '*weak*' during energy restriction, '*dizzy*', '*light-headed*' and '*headaches*' during fluid restriction and '*fatigued*' during training. In order to achieve BM loss through energy restriction, many of the athletes reported a reduction in '*junk foods*' and also '*fat*' and '*carbohydrate*' intakes. Post weigh in a large focus was on immediate food and fluid intake, with '*energy*' '*carbohydrates*' and '*water*' cited as the most common responses.

The main influences on BM loss from this data is also in agreeance with other studies conducted in combat sports, whereas coaches, training colleagues and other competitors, are cited as the most common effectors in the decision to reduce BM for competition. However, interestingly it was highlighted that parents have a large amount of influence on Cadet and Junior division athletes below the age of legal responsibility as described in section 2.6.8. This highlights the necessity to engage with these stakeholder groups, to further understand their perceptions of the making weight practices of the differing age divisions and the requirements of BM loss between OG/WT weight categories. Additionally, this may highlight the perceptions of influence between coach and parent groups, affording a greater understanding of their motivations in the encouragement of making weight practices. Furthermore, each stakeholder group may also elucidate the most efficient mediums to provide targeted educational packages, which may change making weight behaviours and allow the formulation of safe and efficient BM loss strategies.

In tandem with making weight practices this study is the first to examine ergogenic dietary supplement use and doping histories, solely on an international standard Taekwondo population. Many of the athletes in both sexes and all divisions use a large amount of '*energy*' based nutritional products including bars, gels and drinks and this is more than likely linked to increasing energetic intake via CHO post weigh in. This trend continues with the use of caffeine being reported in qualitative responses for '*performance enhancement*', green tea for '*weight loss*' and fish oils/vitamins for '*health benefits*', in agreement with other studies conducted on combat sports (Kordi et al., 2011) and other sports in general (Suzic Lazic et al., 2011). The use of β-Alanine, creatine, sodium bicarbonate, tart cherry juice and casein/soy/whey protein, manifested limited qualitative responses. However, many of the athletes reported having no knowledge of their purported benefits, or whether the product had been tested for banned substances under the WADA code, which is distressing considering that at least 23% of Senior division athletes had reported conducting a doping test (Campbell et al., 2011).

3.5. Conclusion

This study confirms that the BM loss occurrences, magnitudes and methods in the Olympic combat sport of Taekwondo do not differ between athletes of differing sexes. However despite this, these factors do differ between the age divisions, which may be attributable to the decreases in the amount of weight categories and expansion in category differences. This study additionally highlights some of the highest combat sport BM loss ranges within the literature, particularly in the OG categories. Again in agreement with previous research, both training colleagues and coaches were identified as the main stakeholder groups influencing the engagement in these practices, however, parents were also identified as key influencers in the Cadet and Junior divisions. Finally, the ergogenic dietary supplement use in this study cohort appeared to be linked to supporting making weight practices in the form of BM loss and performance enhancement pre and high energy aids post weigh in. Alarmingly, and despite a high prevalence of ergogenic dietary supplement use, athlete knowledge and understanding of how to scrutinise these products for potential anti-doping violations was largely poor despite all being eligible and many having conducted an anti-doping test.

CHAPTER 4.

Stakeholder Perceptions of Making Weight and Nutritional Practices in International Standard Taekwondo Athletes.

4.1. Introduction

The findings of Chapter 3 further support previous evidence that international standard Taekwondo athletes engage in making weight practices linked to BM loss. However for the first time, this study demonstrated there are key differences in practices and behaviours between age divisions, which may be linked to the decreases in weight categories and increases in category differences. Chapter 3 along with numerous research investigations (see section 2.6.8), have synonymously established that coaches are often one of the main influences on combat sport athlete making weight and nutritional behaviours. There is also emerging evidence to suggest that for those athletes below the age of legal responsibility, this influence is further mediated by parents (Sansone & Sawyer, 2005; Xiong et al., 2017), which was additionally confirmed in Chapter 3. Despite these findings, qualitative investigations may aid in further evaluating the wider stakeholder attitudes, beliefs and knowledge surrounding these influences (see section 2.6.8). This has been previously conducted in other non-combat making weight sports, highlighting contextual stakeholder perceptions, which were further explored to enhance positive changes to practices and behaviours via education and improved policies/procedures (Martin et al., 2017).

Chapter 3 also highlighted that ergogenic dietary supplement use in this population may be linked to BM loss practices pre and post weight in. Various research studies have examined the nutritional and ergogenic dietary supplement use in combat sport athletes, either inclusive or exclusive of making weight practices and across varying preparatory or competitive periods (see section 2.8.2 and 3.1). Whilst these investigations provide useful data to assess both dietary macro/micronutrient content and feeding/ergogenic dietary supplement frequency and distributions, they do not present any detailed information on the motivations, which encourage the engagement in these behaviours. Studies by Pettersson et al. (2013); Pettersson et al. (2012), have explored these themes in greater detail in a group of Olympic combat sport competitors (inclusive of Taekwondo athletes), but further research is required to assess the additional key stakeholder perceptions of these practices within this demographic.

Pettersson et al. (2012) suggests that combat sport athletes are in a constant struggle between non sport related concerns/bodily requirements and the sport specific demands of making weight for competition. Particular themes emerging from this study were the athletes concerns with body image and the importance of physique. However, in various investigations examining this factor in combat sport athletes generally, studies indicate that despite potential contrast between sexes (Rouveix et al., 2007), there are no discernible differences between those combat sport athletes who engage in BM loss and normal controls (Costarelli & Stamou, 2009; Filaire et al., 2007). Further to this, Pettersson et al. (2013) have also suggested that the cultural making weight practices in combat sport represent a key part of the athletes' identity, mental diversion and mental advantage during the competitive preparatory period. However, no study has subsequently explored this theme and further examination of this paradigm is certainly warranted.

Therefore, the aim of the present study was to examine the overarching perspectives of various key stakeholders within the combat sport of Taekwondo, to garner a greater understanding of their perceptions on the influences which encourage engagement in specific making weight and nutritional practices.

4.2. Methods

4.2.1. Participants

To gain the greatest insight into the perceptions of differing stakeholders within the demographic, a purposeful sampling approach was taken, inclusive of variation in sex, weight category, experience and previous involvement in the sport, to provide a balanced perspective of the research question (Patton, 2015). Participants were sectioned into three stakeholder groups inclusive of Athletes (3 males & 2 females), Coaches (4 males & 1 female – 3 previous athletes & 2 non-athletes) and Parents (3 males & 2 females – 2 active sporting involvement & 3 non-active sporting involvement). All participants were above 18 years of age with athlete's inclusion criteria stipulating: (a.) 1st Dan black belt, (b.) global athlete licence (GAL) and (c.) at least 3 years' international competition experience. Coaches inclusion criteria stipulated: (a.) global officials licence (GOL), (b.) continental union license (CUL) and (c.) at least 5 years' international coaching experience. Only parents of athlete's inclusion criteria were sampled. Ethical approval was granted by the Liverpool John Moores University research ethics committee and all potential participants were contacted via e-mail requesting their involvement in the study of which 100% agreed to engage with the investigation. Participants provided informed consent by return of e-mail after disclosure of the study's aims in a participant information sheet. Confidentiality was guaranteed for all participants and only limited details are provided throughout i.e. Athlete 1, Coach 2, Parent 3 to ensure anonymity.

4.2.2. Data Collection

Semi-structured interviews were conducted with all participants, with questions designed taking into account previous quantitative and qualitative investigations (see section 2.8), as well as the observations made in Chapter 3. Question structure was arranged to cover a broad range of topics including BM loss habits/magnitudes/time courses/methods, nutritional knowledge/practices, the importance of physique and key influences (see Appendix 2). An open-ended question format was adopted to allow voluntary contribution and detail in an informal conversation (Lincoln & Guba, 2006). This format allowed each participant to express their insights and emotions with minimal constraint, so to navigate towards areas of significance. Probing was employed when required, to obtain more depth to specific answers (Gratton & Jones, 2010; Turner, 2010). Prior to the beginning of the study a pilot interview was conducted with a previous athlete and current coach in order to refine the questions and to assess the efficacy of the measurement tool in addressing the research aim. Interviews were conducted via telephone and were recorded to be subsequently transcribed, with the average interview length being 36 minutes (range 22 – 47 minutes). The interviewer was acquainted with the sport, having previously competed as an international level athlete for 10 years and also currently being an Olympic licensed coach. Whilst this can be viewed to negatively impact data collection in terms of leading participants' responses based on personal views and experiences (Creswell & Creswell, 2018), conversely this was viewed to facilitate the process. Given the interviewers experience with the sporting jargon and informal terminology, being viewed as an insider by the participants was more likely to elicit more meaningful and truthful responses (Abramson & Modzelewski, 2011).

4.2.3. Data Analysis

All interviews were transcribed verbatim generating 131 pages of text (41 athletes; 44 coaches; 46 parents). Utilising a parallel content and thematic analysis approach (Braun & Clarke, 2006; Elo & Kyngas, 2008; Vaismoradi et al., 2013), multiple readings of the data were conducted to allow immersion in the detail. For the initial topic of identifying BM loss habits/methods/time courses/magnitudes, content analysis was used to examine frequencies in responses and generate specific codes. For all subsequent sections, thematic analysis was utilised to describe themes within the data, where there was commonality between participants' responses. Once both codes and themes had been identified these were then organised into a series of data matrices (Miles et al., 2014) to allow a more practical view of the emerging narrative. These matrices were subsequently reviewed, which allowed a cohesive story to develop between the varying participant stakeholders, generating an encompassing perspective of the data (Martin et al., 2017).

Transparency was achieved by having other members of the research group independent from the primary author and providing critique for all phases throughout the data collection and analysis.

4.3. Results

Within this section the results are divided into six subcategories to examine the perceptions, beliefs and attitudes of the differing stakeholder groups in parallel. Section 4.3.4 also includes a specific focus on the individual insights of the Athlete group, with additional reference to their seasonal nutrition/ergogenic dietary supplement knowledge and practices. Section 4.3.6 focuses on the support network group (Coaches/Parents), with further reference to their considerations on potential policy and procedural change.

4.3.1. The Culture of Making Weight Practices

The magnitudes, occurrences, motivations and insights of both BM loss and making weight practices are presented in Appendix 3.1. Independent of sex, the magnitude of BM losses expressed by the Athlete group ranges from 3-8 kg, achieved in periods of 2-5 weeks (14-35 days). Further probing in both the Coach and Parent groups, also validated that there were differences in the magnitudes and time courses of BM losses between the Cadet, Junior and Senior divisions. Both groups synonymously expressed that Cadet athletes were discouraged from losing amounts greater than 2 kg over any period longer than two weeks (14 days), whereas there was an acceptance that athletes needed to lose more BM as they progressed through the age divisions. Coaches 1/5 and Parent 5 stress the reasoning behind the unwillingness to engage younger athletes in more protracted BM losses and periods is due, in part, to the fact that this age demographic are *'still growing'*. However, in an additional excerpt, Coach 5 also states: *'I've been sanctioned before…somebody left my team who basically told the child safeguarding authorities what we did and apparently it was wrong so I got a warning. Now I won't advise losing any more than that amount of weight'* insinuating the reluctance is also driven by fear of higher authoritarian intervention. Interestingly, Parent 4 also highlights the difference in the amount of categories between the age divisions, stipulating it was easier when her child was younger given the greater range of categories. The occurrence of these BM losses are dictated by the new competitive calendar, with all stakeholders expressing that this typically occurs between 10-12 times annually. This is based on the need to compete each month to every few weeks and is independent of either sex or age division.

Regardless of sex, all participants in the Athlete group highlighted that the key motivation for engaging in BM loss, was to be more competitive in both stature and BM. Interestingly, there was a dissonance between the reasoning for this, with Athletes 1 and 4 expressing that they would achieve *'advantages'* over other opponents due to their stature, whereas Athletes 2 and 3 highlighting their motivation was to *'level the playing field'* against the type of competitors who possess anthropometric dominances. From all Coaches perspectives, there was an acceptance that making weight practices are an inherent part of the weight categorised nature of the sport and this was something that would always be part of its culture. However compellingly, Coaches 1, 2 and 3 who are all previous athletes, accentuated their disagreement with the practice of making weight. More so, Coaches 4 and 5 who were not previous athletes highlighted the importance of making weight to competitive accomplishment expressing statements such as '*If you want to be successful its fundamental' and 'I think it's a necessity in order to win'.* Parent group insights on making weight practices seemed to reaffirm both the perspective of Athletes and Coach groups, with all agreeing it is culturally intrinsic to lose BM for competitive advantages in Taekwondo competition. Highlighting a specific instance from Parent 4, there almost seemed to be a justification of these behaviours exhibited in the statement *'...I'd rather have her in a weight group where I know she's going to come up against other athletes that are roughly her size because at the end of the day, she would get kicked left, right and centre'* seemingly indicating a maternal instinct in prioritising safety in competition at the expense of exposing the athlete to the risks of excessive BM losses.

4.3.2. Methods of Body Mass Loss and Psychological and Physiological Symptoms

As highlighted in Appendix 3.2, the participants in the Athletes group utilised a multitude of methods, in order to achieve their respective BM losses. All Athletes described engagement in energetic restriction, particularly via reducing or excluding CHO based foods, concomitant with reductions in both meal size and frequency. Additionally, all Athletes also discussed how they would increase the volume and/or intensity of exercise they engaged in, to further exacerbate energetic deficits. Interestingly, Athletes 1 and 5 also discussed the use of fasted exercise and when further probed, expressed this was to deliberately target the loss of FM. Furthermore, all Athletes also conveyed that in the final days leading into a competition weigh in, techniques of both active and passive dehydration played a unique part of their individual BM loss strategies. All Athletes highlight the use of '*sweat suits'* and *'increased layers'* in training, concurrently with reduced fluid intake. Athletes 1, 3, 4 and 5 also discussed using saunas as a means to further reduce BM, with Athlete 5 elucidating a unique individualised strategy: *'…the day before the weigh in I'd just drink little espresso shots to dehydrate me a bit more'*. When questioned about this, the Athlete voiced how they felt it would make them urinate more to further induce dehydration. All of the Athlete group described how these practices made them feel physically *'fatigued'*, *'tired' 'unable to maintain training intensity'* and *'dizzy'* whilst psychologically being a *'mentally tough process'*, which resulted in *'decreased motivation', 'mood swings'* and *'mental breakdowns'*. Adding further context to this process, it seems apparent that none of the Athlete group had any desire to engage in these practices, based on the psychological and physiological symptoms that they experienced, with Athlete 3 particularly stressing: *'Awful. Absolutely disgusting. It literally made you question why I competed every time I did it'*. However further to this they also highlighted: *'I guess like most athletes you kind of just got on with it. You just learnt to accept things and it became normal'*, a view that is further supported by Athlete 5: '*It just consumed you, like all I'd think about, probably 90% of what was on my mind would be related to weight in some kind of fashion…Everything was kind of related back to weight as opposed to just living life'*.

The Coach and Parent groups confirmed many of the methods and psychological and physiological symptoms described by the Athlete group. Additionally, to this, Coaches reported how many of their Athletes demonstrated reduced *'cognitive functioning'* and *'reactiveness'* throughout training and sparring sessions. Alarmingly, both of these groups highlighted additional methods and physical effects that were not elucidated by the Athlete group. Both Coach 5 and Parent 3 remark how they have witnessed the implementation of extreme practices, including the use of diuretics and laxatives, with both Parent 2 and 3 also describing physiological abnormalities including amenorrhea and chest pains. Furthermore, Coach 5 also describes how far athletes are willing to go in order to meet their weight category limit*: 'I even saw a girl once at a German Open and she basically drained herself for God knows how long, how many days, weeks and she still couldn't make her weight so she cut her hair. She had the most beautiful hair, it had been well looked after and she cut it off, cut all her hair off! And she lost in her first match! [laughing]'.* Continuing from their disagreement with making weight practices highlighted in the previous section, Coaches 1, 2 and 3 all express their disapproval of athletes engaging in these processes, with Coach 1 specifically relating this back to their own negative experiences as a former competitor. Coaches 4 and 5 describe the *'simplicity'* of the process and how they *'advise'* on methods to lose BM. Both of these individuals also describe how they believe the use of more deliberate practices in Senior division athletes are warranted, with Coach 4 stating: *'With senior, yes we have done dehydration before but that's a senior, they know what they're buying into. They can give you a little bit more context, you know'.* Interestingly, Parent 3 also confirms the Athlete point of view about the acceptance of the making weight practices within the sport by stating: *'It's a mind-set that they know they're going to be losing weight to compete and that's what they do. It just seems to be a thing now for any group of Taekwondo players that there's a level of 'oh I'm cutting weight' or 'yeah I'm fighting in three weeks' or 'I've got three days to weigh in'.*

4.3.3. Body Image and the Importance of Physique

Additionally highlighted in Appendix 3.2, all stakeholder groups unanimously agreed that physique was of insignificance, in comparison to the key goal of losing BM to meet a weight category limit, however, a number of interesting themes emerged from this paradigm. All Athletes commented that despite their main goal being to make a specific weight category, paradoxically they were not happy with the way they looked in doing so. Both Athlete 1 and 3 describe how making a stipulated weight category was their only concern, however *'being skinny wasn't very nice'* and *'I didn't really like the way I looked at 63s'*. The Coaches group focus on the primary target of making a specified weight category, is also tantamount to the importance of having a particular body shape in order to perform. However, this is in direct conflict with the desire for the athletes to also *'look healthy'* as in the case of Coach 4 who states: *'The real main important thing to me is kind of (a) are they healthy, (b) are they performing? The general looks of the athlete's body, obviously if they are skin and bone it's a problem, you want them to look lean, you don't really want bones showing here, there and everywhere, but at the end of the day they need to make the weight'.* The Parents group views are divided between those who have either active or non-active sporting involvement, with Parents 1 and 2 highlighting the importance of physique for performance and Parents 3, 4 and 5 stipulating the importance their child's health independent of physique. Parent 4 also describes antinomy between this concept: *'Taekwondo players, they're all literally near enough the same physique. They've got wide shoulders, small hips and you know, quite slim legs. For me it's important for my daughter to look like this but not at the cost of killing herself for it'.*

4.3.4. Nutritional Knowledge/Practices Throughout the Making Weight Process

Appendix 3.3 highlights the nutritional habits of the Athlete group post weigh in, on competition day and post competition periods alongside the perspectives of all groups on the Athlete group nutritional knowledge and practices.

In the initial post weigh in phase, all Athletes stress the importance of fluid ingestion with individualised strategies ranging from the use of re-hydration solutions, to large volumes of fluids across both immediate and prolonged timeframes. The majority of the group also stress the importance of CHO ingestion in this period, despite a number of differing approaches to re-feeding strategies. Athletes 2 and 3 both describe a hyperphagic response via gorging on convenience foods high in fat and sugar, stressing their reasoning behind this is due to the prolonged nutritionally restricted period they have endured and to satisfy cravings. Athletes 1 and 4 describe their desire to follow this strategy, yet note the negative impact this would have on their competitive preparation for the following day. Indeed, Athlete 3 describes how their sleep is negatively affected the night before competition*: 'So it was kind of crammed, I used to not sleep the night of a competition because I'd probably over carbed or had a sugar rush or what, I don't know. It just used to make me feel sick'*. Athlete 5 describes a much more phasic approach to re-fuelling post weigh in, but yet again describes allowing themselves a reward in a high calorie snack.

On competition day all of the Athlete group still stress the importance of fluid ingestion throughout this period. Interestingly, all of the group describe how they would focus on eating a breakfast high in CHO prior to the start of competition, given certain individuals describe struggling to eat throughout the day, due to the feeling of nervousness. Athlete 1 also describes how given the period of BM reduction can reduce stomach volume, they utilise a strategy of feeding little and often to avoid any gastrointestinal distresses. This strategy is described by Athletes 3, 4 and 5 who all testify to eating small snack foods high in CHO (particularly sugar), to energise them throughout the day, with a more substantial feed during a break between contests. Intriguingly, Athlete 2 describes how they try to eat at breakfast but will typically focus on only fluid ingestion during the competition day. When probed further on this the Athlete remarked: *'I think it was just down to nerves. I've never associated with eating on the day of competition with performance, sort of thing'.*

In the post competition period, all Athletes describe a period of rebound hyperphagia where they feed on a number of junk/convenience foods inclusive of alcohol. All Athletes report how they are psychologically drawn to these foodstuffs, without having plausible explanations as to why. Highlighting this further, Athlete 3 describes: *'You deplete yourself of so much for weeks, you just want it, you don't even need it but you want it it's hard to explain'.* Most Athletes also stress how after a set uncontrolled eating phase, they deliberately return to a controlled period of eating *'healthily'.* When probed many of the Athletes recount how this is a strategy employed in fear of increasing BM too far in excess of their weight category, as discussed by Athlete 4: *'…Then I would convert back* *to protein and vegetables so I never try to go above 61 kg. If I did I always knew it would be a lot harder for me if I saw that my weight rebounded back to about 62, 63 kg and I was like it's going to be a lot harder to drop my weight if I'm competing in the next three weeks'*. However, despite this Athlete 2 showed little concern in controlling their eating habits for BM regulation stating*: 'I'd say it (nutritional habits) goes downhill even more so in the off-season. I just sort of pig out at Christmas, loads of chocolate, Coca-Cola, alcohol. I don't really want to think about making weight in this period until the next time I have too'*.

In regards to opinions of their own nutritional knowledge, all of the Athlete group describe how they felt the need to be better educated in this area. Most of the group discuss how eating via optimal nutritional practices is an expensive enterprise, with some also remarking the diet period they employ during BM reduction being mediated by this factor. Many of the Athletes also stress how preparing food *'to eat well'* takes considerable time, plus having a lack of *'motivation'* to cook meals due to post training *'tiredness'*. Further to this some of the group report how other external influences including *'training partners'* and *'coaches'* impact on their nutritional practices, with Athlete 5 describing: *'I 100% know the right things to be eating and when to be eating. I definitely know, kind of, all of that stuff. I think sometimes it is just about putting it into practise, that side of things sometimes I was kind of lacking'*. When examining the Athlete group understanding of ergogenic dietary supplements (see Appendix 3.4), a number of interesting themes emerge. Athletes 1, 4 and 5 all state the use of ergogenic dietary supplements, with products ranging from vitamins and minerals, β Alanine, creatine and electrolyte solutions. Athlete 3 also remarks how they do not utilise these supplements, yet when further probed describes using protein shakes, whereas Athlete 2 states they do not use these supplements due to both cost and fear of potential inadvertent doping violations. Athletes 1, 4 and 5 all mention utilising an online checking service to scrutinise these products for safe use.

Both Coach and Parent groups confirm a number of the aforementioned key themes i.e. post weigh in hyperphagia, re-hydration, budgetary constraints etc. however, report a number of conflicting ideologies in their own perceptions around the Athlete group nutritional knowledge and practices. Despite many of the Athletes describing an adequate level of knowledge, many of the Coach group express how this is not the case with Coach 2 remarking: *'...So, I think, for them, it's more about making weight, it's not about how they make the weight and it's not about is this going to be good for them? Or is this going to help their performance? So I think their knowledge is very limited'*. Many of the Coaches also report how the Athlete group receive advice from both them and external national team/governing bodies, yet often do not employ this adequately with Coach 1 stating*: 'Well they should have the knowledge, I mean I help them out with what they should be eating and I look at their diets, if they're trying to come down a little bit then I try and swap things over...So the knowledge is readily available but they don't tend to follow it very strictly, in my opinion'.* Conversely, many of the Parent group describe how the Coach group are not adequately educated to provide this information and the deficit in the Athlete group knowledge is attributable to this, as described by Parent 2*: 'You never get a bad player, you get a bad coach and so if the coach is not relaying the right information it is going to go down into the players. The coaches need education, that's 100%'* and Parent 4: *'There really isn't enough out there, the coaches didn't explain to her enough about nutrition'.*

4.3.5. Influences on the Engagement in Making Weight Practices

The influences on the engagement in making weight practices are highlighted in Appendix 3.4. The Athlete group synonymously describe coaches, training partners and other competitors, as the main precipitators behind the motivation to engage in these practices. Furthermore, Athlete 5 also reports: *'I was kind of my main driver. I guess selection policies and Olympic weight categories don't help though'* indicating that these factors also infer influence. The Coach group, described as the main influence by the Athlete group, in most instances acknowledge that this is correct. However, the Coach group also illustrate that the Parent group are another main mediator behind the influence of Athlete making weight practices, particularly when under the age of legal responsibility. Coach 2 states: *'...if I'm being honest, parents. It's crazy how much a* *parent can motivate their child to make weight it really is'* and this is further supported by Coach 4: *'I think at Cadet and Junior level the parent plays a massive part because they either make or break an athlete. They either push them to a point where it's just, it's wrong, so I think sometimes it's the parent that has the main kind of pivot on them'*. Surprisingly this view is also confirmed by the Parent group, however, with many describing how they have witnessed the extreme practices of others such in the case of Parent 1: *'I found out his dad had them on laxatives, a fucking 14 year old boy. You know we put a stop to it straight away like'* and Parent 3: *'It's difficult because nobody will tell you that they're forcing their child to lose weight will they so I think with a lot of kids it is parents…'*. The majority of the Parent group also stress how coaches are still the main driver in the influence on the Athlete group to make weight with Parent 3 remarking: *'I do believe that certain coaches who influence their policy to, as you can see some coaches they go away or they go to competition and they're all in sweat boxes, they're all sat round and this is not Seniors, this is Juniors and they're all desperate for weigh in to open'* and Parent 4: *'I know, like, some coaches say to them 'look, we need to, you need to drop them down' so I do think coaches sort of force the issue sometimes'*. Furthering the earlier point made by Athlete 5, a number of both the Coach and Parent group state how national team selection policies are also a key driver in influencing practice, further described by Coach 1*: 'Well within the national team it's the coaches and the pressure to perform at the weights that they're selected…'* and Parent 5: *'The national team and selection policies do have an influence. When you get selected to represent your country you want to do it don't you? You don't want to go 'look, I can't make this weight' So it's very difficult for them to resist doing it either rightly or wrongly'*.

4.3.6. Perceptions of Coaches and Parents on a Need for Change

Appendix 3.3 further highlights the perceptions of the Coach and Parents groups on a need for change. A number of the Coach group, address how they have little regard for the current making weight policies and provisions provided by both the national governing body and respective national teams. Both of these stakeholder groups synonymously express that the key to addressing the culture of making weight within the sport is a more detailed educational programme. However, despite this, there is disparity in the way each of these groups perceive this information should be delivered, with a number of ideas inclusive of lectures from experts, discussions, website materials etc. which needs to be readily accessible to all stakeholders. Intriguingly, the majority of participants in both the Coach and Parent groups, highlight that this education should be primarily delivered to the coaches rather than directly to the athletes. When further probed on the reasoning behind this Coach 2 expresses: *'I think the coaches need more guidance. If you're looking at a Cadet, Junior, anyone under 18, you are influenced by your coach, by your peers and parents, so if the advice you're getting is wrong at that age, that's habit forming…'* with Parent 3 reinforcing this idea by stating: *'I think that we really, really need to start at the top with coaching. I think a lot of coaches need to understand the nutritional advice should be given a lot more…whether we like it or not the weight loss thing's here to stay so at least let's get some education out there. Let's have parents, coaches and athletes making informed decisions rather than what I see today.'* Finally, some of the Parent group also comment on the current weight categories and how change on a broader scale should be mediated by the global federation, in trying to set a greater number of categories, particularly at the Olympic based events.

4.4. Discussion

The main aim of this Chapter was to examine the overarching perspectives of various key stakeholders identified in Chapter 3. This was to garner a greater understanding of perceptions on the influences which encourage engagement in specific making weight and nutritional practices, within the Olympic combat sport of Taekwondo. With no apparent differences in the perceptions of stakeholders based on group or sex, all participants synonymously confirm the magnitude and occurrence of BM losses, that have already been reported quantitatively amongst Taekwondo athletes both in the literature (see section 2.6.6) and also Chapter 3. This data also affirms quantitative findings highlighting differences between the BM loss amounts and practices among combat sport athletes of differing age divisions, as highlighted in section 2.6 and Chapter 3. However, interestingly it appears that this is being mediated by both the Coach and Parent groups, rather than by the Athlete group themselves *per se*, further confirming the findings of Chapter 3.

Pettersson et al. (2012) and Kristiansen et al. (2008) noted that despite the stresses induced by making weight practices in combat sport athletes, there is an acceptance that these are normal part of the preparation process for competition, as also highlighted in other non-combative making weight events (Martin et al., 2017). An intriguing theme emerging from this study, are the apparent differences in the perceptions of making weight between the Coach group. This paradigm has been previously examined in a study by Umoren et al. (2001), who also emphasised the differences between coaches with or without prior competitive experience, highlighting no correlation between previous competitor coaches and the advocation of BM loss for competition. Parent group perceptions follow the same introspection as the Coaches group, which was particularly stressed for those in the younger age divisions, in agreement with a study by Weissinger et al. (1991), who highlighted the same parental perceptions for a cohort of youth combat sport athletes. However, an interesting observation amongst the Parent group is an understanding and in some cases a justification, of why younger athletes need to engage in more extreme making weight practices as they progress throughout the age divisions.

This is only the second study to qualitatively provide detail as to why combat sport athletes engage in making weight practices. Typically, the majority of the combat sport literature describes that these athletes lose BM for advantages in either stature, limb length or for a greater power to mass ratio over opponents (Pettersson et al., 2013). Whilst the results of this study agrees with this assertion, there is a clear division in the Athlete group between the paradoxical desire to gain and/or reduce advantages in physicality amongst competitors. It has also been demonstrated previously that not all combat sport athletes believe that BM loss is tantamount to competitive success (Kordi et al., 2011), yet both the Coach and Parent group stakeholders confirm in this study that *'height'* and *'reach'* are important for advantage in the sport. Conversely to Pettersson et al. (2013), none of the Athlete group expressed any positive associations via sporting identity or mental advantage in regards to the practices of making weight. In parallel to another enquiry by Pettersson et al. (2012), the Athlete group describe their abhorration in having to engage in BM loss for competition. However, in agreement with many other investigations reported in the literature, all of the stakeholder groups identify that this is an inherent part of the sports culture.

In conflict to the findings of Pettersson et al. (2012), all of the stakeholders placed little importance on the value of body physique, however, contradictorily there were a number of conflictions between stakeholder perceptions. Despite the Athlete group (independent of sex) describing a dislike of their physique at differing stages in the making weight process, a number of investigations have highlighted that combat sport athletes do not demonstrate any protracted body image dissatisfaction issues in comparison to normal controls (Costarelli & Stamou, 2009; Filaire et al., 2007). However, this confliction is not uncommon in those athletes who strive for 'leanness' (Kong & Harris, 2015). The Coach and Parent groups describe convoluted perspectives of athlete body physique, that are in contention between the ideologies of both performance and health. Taking into consideration the similar perceptions of making weight practices, from a coaching perspective this appears to be a classical example of espoused vs. enacted values (Lyle &

Cushion, 2013), whereas many of the comments from the parent insights indicate more indistinct views arising from cases of cognitive dissonance (Festinger, 1962).

The nutritional practices of the Athlete group, across a number of differing periods are in stark agreement with the findings of Pettersson et al. (2012). Varied perceptions within the group, highlight fascinating insights into the struggle with post weigh in hyperphagic behaviours and demonstrate the conflict between focusing on subsequent competitive performance and reward. The discussion about the importance of fluid ingestion and a continual intake of CHO rich food sources, is again in agreement with the observations in Chapter 3 and also Pettersson and Berg (2014). The individual strategies, including not eating throughout the day to manage competitive nerves, are similar to those described by Pettersson et al. (2012), along with the ideology that post weigh in period CHO food sources are a friend, yet pre weigh in they are definitively an enemy to the primary goal of losing BM. The description of rebound hyperphagic behaviours in the post competitive period have been characterised in the literature particularly after periods of semi starvation (see section 2.9). However, in specific cases, the descriptions of the Athlete group exhibit signs of disordered eating habits, characterised as common practice amongst combat sport athletes (Sundgot-Borgen & Garthe, 2011). Highlighting an individual case, a participant in the Coach group describes how they feel these processes may contribute to BM gain later in life: *'…this is another thing, when somebody retires from Taekwondo and they had to lose a huge amount of weight, they just balloon out for some reason…I mean I used to compete at -64 kg and I'm 95 kg now…All the coaches that used to compete in my time might be 20, even 30 kilos over the weight that they were when they used to compete and surely that shit can't be healthy you know?'.* This appears to be a description of a previously characterised concept, where weight cycling is postulated as a contributing factor to FM overshoot in subsequent middle age, which has been linked to extreme depression and suicidal tendencies post competitive career (see section 2.9).

The majority of the Athlete group describe a paradoxical view of how they have an adequate knowledge of nutrition, yet would seek to be further educated within the area.

Disturbingly, there is limited awareness of how to scrutinize ergogenic dietary supplement use in agreement with the findings of Chapter 3. The majority of the group state they use the online website Global Dro, which can only be employed for examining medications and highlights the ineptitude within this area, yet this is not uncommon amongst elite sporting groups (Garthe & Maughan, 2018). The nutritional decisions of this group appear to be influenced by a number of multifaceted factors, which are complex and dictate subsequent behaviours (Sobal & Marquart, 1994). Factors such as cooking skills, time and expense of eating healthily for competition, have all been previously characterised in a host of athletic populations (Birkenhead & Slater, 2015). Athlete group descriptions of coaches and team mates being key influences in not only their nutritional habits, but also their making weight practices is unsurprising, given the multitude of research highlighting this synonymously amongst combat sports and also in Chapter 3. Alarmingly when further probed, many of the Athlete group state this is because they perceived these stakeholders to be the foremost source of information as previously described by Marquart and Sobal (1994).

This study presents the first time that external stakeholder groups such as coaches and parents have been qualitatively assessed for the actuality behind athlete views on their implied influential behaviours within the sport of Taekwondo. The majority of the Coach group agreed, that they have a substantial influences on their athletes' nutritional and making weight behaviours, in agreement with Weissinger et al. (1993), who described how many of the surveyed combat sport coaches in their study felt athletes were forced to engage in BM loss for competition. Furthermore, there is clear confliction between both Coach and Parent groups views, on both the coaches impact and knowledge of athlete making weight and nutritional behaviours. In consensus, a number of studies have highlighted that despite combat sport coaches being the primary source of both influence and information for these factors in athletes, their beliefs, attitudes and knowledge does not qualify them to act adequately in this capacity (Sossin et al., 1997; Umoren et al., 2001; Weissinger et al., 1993). Additional stakeholder groups comments on the inferred influence of national team selection strategies, despite the provision of safe making weight policies, yet again implies organisationally mediated espoused vs. enacted values in ultimately driving the culture of making weight within this demographic (Fletcher & Hanton, 2003; Gould et al., 2002). Encouragingly, both the Coach and Parent groups perceptions, that education is needed among all stakeholder groups (coaches in particular), is in consensus with previously described studies (Sossin et al., 1997; Umoren et al., 2001; Weissinger et al., 1993) and also Franchini et al. (2012), who provides a number of guidelines in order to achieve this aim.

4.5. Conclusion

The present study highlights for the first time the perceptions, beliefs, attitudes and knowledge of key stakeholders on the making weight and nutritional practices currently undertaken within the sport of Taekwondo. Despite stakeholder understanding of the psychological and physiological stresses and potential dangers of current practice, this is culturally inherent due to the perception of gaining and/or reducing opponent competitive advantages and is unlikely to desist in the future. There are obvious convoluted ideals between both coach and parent views in regards to this, with both espoused vs. enacted values and cognitive dissonance being displayed. Despite both the Athlete and Coach groups believing they have an adequate knowledge in the areas of making weight and nutrition, there is a genuine desire to gain an enhanced understanding, with all stakeholders agreeing that a change in approach to current practice is needed. All groups describe the need for the national and global governing bodies to address this issue, by providing a better level of education for those stakeholders engaged in both the practice and advisement of making weight for competition.

CHAPTER 5.

Magnitudes of Body Mass Loss Between Olympic and World Weight Categories and Measurement of Body Composition Indices in International Standard Taekwondo Athletes

5.1. Introduction

A number of studies highlighted in Chapter 2 (see section 2.6.8) and the data from Chapters 3 and 4, have emphasised the making weight practices of international standard Taekwondo athletes. Given the official weigh in is held the day before competition, it is common for these athletes to lose BM to compete in the lowest weight category possible, in the belief of gaining competitive advantages in stature, limb length and power-to-mass ratio. Chapter 3 demonstrated that Taekwondo athletes lose differing magnitudes of BM dependent on their targeted WT or OG weight category, ranging from up to 7-10% and 16-18% between sexes, respectively. These results could be considered unsurprising given the OG weight categories have some of the largest category differences between combat sport disciplines (see Table 2.7). Examining the BM loss requirements of those athletes who compete in these differing weight categories is crucial in understanding how this may be achieved and in consideration of the next day re-weigh in ruling limiting gains in BM to 5%.

Chapters 3 and 4 highlighted that typically these BM losses are accomplished in both acute and chronic timeframes, via restriction of EI and increased AEE, concomitant with both active and passive dehydration techniques. Emerging evidence suggests that reductions in EA, may manifest into RED-S syndromes causing a range of health and performance related consequences (see section 2.8.5). On this basis, it is vital for these athletes to compete in the most appropriate weight category in relation to LM, with the loss of FM being regarded as the most efficient way to reduce BM (Langan-Evans et al., 2011). To assess the potential for reduction in these tissues, multi-compartmental body composition measures such as Dual X-Ray Absorptiometry (DXA) are recommended as the reference assessment method in athletic populations (see section 2.2.1). Given DXA allows the examination of tissues in specific body regions, this can be useful to highlight intra/inter weight category differences and is crucial in providing key information to prescribe EA status for training and nutritional interventions when targeting effective BM losses.

In a sport specific context, more practical methods of body composition analysis such as anthropometric $\sum_{SKf}$ assessments and subsequent use of prediction equations to estimate FFM and FM% are more commonly utilised in the field. Various $\sum_{SKf}$ prediction equations have been implemented in a number of studies examining the body composition of international standard Taekwondo athletes of both sexes (see section 2.2.1). Given many of these equations often derived from hydrodensiometry conducted in general populations, there is limited scope for their use in athletic demographics. As such, there is a large disparity between FM% exhibited across the research literature and an examination of which $\sum_{SKf}$ equation may provide the most valid assessment of FM% in relation to a criterion method such as DXA is warranted (Bridge et al., 2014).

Therefore, the primary aim of the present study was to examine the BM loss requirements of international standard Taekwondo athletes for their respective WT and OG weight categories in the days prior to a competition weigh in, whilst concurrently assessing body composition utilising both DXA and anthropometric $\sum_{SKf}$. A secondary aim was to establish DXA derived values of whole and regional body composition in these athletes, whilst comparing the validity and accuracy of FM% established from several commonly utilised $\sum_{SKf}$ prediction equations, relative to DXA as the criterion method.

5.2. Methods

5.2.1. Participants

Eighteen male Taekwondo athletes (10 Caucasian/8 Black ethnicities, 20 ± 4 years old, 72.0 ± 11.0 kg, 182.8 ± 5.2 cm) participated within the study on the basis of the following inclusion criteria: (a.) >17 years and <35 years of age, (b.) minimum of 1st Dan grade and (c.) >3 years' international competition experience. Participants indicated the WT weight category in which they were entered for competition and were then sub divided based on their elected OG weight category resulting in seven Fly (-58 kg), six Feather (-68 kg) and five Welter (-80 kg) athletes, respectively. All participants were informed of the test procedures and potential risks, written informed consents were obtained and the study was conducted in accordance with the Liverpool John Moores University research ethics committee approval.

5.2.2. Procedures

Body composition was measured via DXA (QDR Series Discovery A, Hologic Inc., Bedford, Massachusetts, USA - software version 12:4:3) using a fan beam, whole body scanning mode and data obtained utilising the DXA Best Practice Protocol (Nana et al., 2015). Prior to scanning, participants were requested to void their bladder/bowels and remove all clothing/jewellery, apart from any undergarments. Stature was measured to the nearest 0.1 cm using a free standing stadiometer and BM was determined to the nearest 0.01 kg on digital scales (Seca 702, Seca GmbH, Hamburg, Germany) for entry into the DXA software system. Both the stadiometer and digital scales were placed on a level surface and participants instructed to remain still during measurements. Positioning on the stadiometer required feet together, with the posterior segments (heels, gluteals, upper back) touching the measuring ruler. Participant head position was neutral (looking directly forwards) and with inhalation/exhalation prior to moving the sliding arm to the crown of the head. DXA system calibration was carried out using an anthropometric spine and step phantom, with a subsequent radiographic uniformity test. Participants were then positioned on the centre of the DXA bed, traction of both the neck and legs was performed to ensure linear spinal alignment, hands were positioned at the side of the participants hips separated by EVA foam padding and feet were turned inwards to the centre line. Once positioned, participants were instructed to remain as still as possible for the duration of the scan. Whole body DXA data including BMC and BMD (individual Z-scores) LM, FM and FM% are reported as the sub-total value (minus the head), as this component measure of DXA represents stronger associations and reduced measurement error than with DXA defined total values (Wallace et al., 2008). Regional DXA data were segmented into trunk and both upper and lower dominant and non-dominant limbs. All DXA positioning and subsequent scan analyses' were completed by the same experienced technician.

Anthropometric $\sum_{SKf}$ measurements were obtained according to the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart & Marfell-Jones, 2011) via an accredited practitioner using skinfold callipers (Harpenden, Baty Int., West Sussex, Great Britain) from eight sites (biceps, triceps, subscapular, iliac crest, supra iliac, abdomen, quadriceps and calf), which were identified and marked prior to the commencement of measurement. Each site was assessed sequentially and then repeated. The equations of Reilly $\sum_{4SKf}$ (Reilly et al., 2009), Durnin and Wormersley $\sum_{4SKf}$ (Durnin & Womersley, 1974), Jackson and Pollock $\sum_{7SKf}$ & $\sum_{3SKf}$ (Jackson & Pollock, 1978), Eston $\sum_{6SKf}$ & $\sum_{2SKf}$ (Eston et al., 2005) and Withers $\sum_{7SKf}$ (Withers et al., 1987) were all employed to predict body density and when required, calculations of FM% were predicted using the equations of both Siri (1961) and Brozek et al. (1963).

All procedures were performed within four days of a competition weigh-in and between 9.00-10.00am to minimise the impact of diurnal, environmental and training factors on within-subject variability. Participants were requested to attend the laboratory after a 12 hour fast inclusive of no fluid ingestion and to refrain from exercise the day prior to assessment (Nana et al., 2012).

5.2.3. Statistical Analysis

Descriptive statistics were provided for all variables (mean ± SD) and data was explored for normality using box plots. Statistical comparisons between weight categories were performed utilising a one way between groups ANOVA and where significant main effects were present, Bonferroni post hoc analysis was conducted to locate specific differences including 95% CI. Additionally, Cohen's *d* effect sizes (ES) were also calculated utilising the following quantitative criteria to explain the practical significance of the findings*: trivial <0.2, small 0.21–0.6, moderate 0.61–1.2, large 1.21–1.99,* and *very large ≥2.0* (Hopkins et al., 2009). For differences between BM loss in the WT/OG categories and LM/FM between dominant/non-dominant limbs, paired T-tests were also performed. The strength of association between $\sum_{8SKf}$, individual SKf sites and DXA-FM% was assessed using Pearson (*r*) correlation analysis. Least squares regression was used to assess validity, where DXA-FM% was regressed individually against each of the ten $\sum_{SKf}$ FM% equations (Hopkins et al., 2009). Fixed bias was assessed by determining whether the intercept for the regression was different from zero and proportional bias was deemed present if the slope of the regression line was different from one. Random error was quantified using standard error of the estimate (SEE) from the regression. Predictive accuracy of each equation for individuals was calculated and evaluated based on the mean of 95% prediction interval (95% PI) for each regression equation and the acceptable anthropometric error rate of 3.5% was set in line with previous suggestions from (Lohman, 1992). Statistical significance was established at an alpha level of $p < 0.05$ and all statistical analyses were carried out using SPSS version 24 (PASW, Chicago, Illinois, USA).

5.3. Results

5.3.1. Comparative and Pairwise Characteristics, Body Mass Loss Requirements and Anthropometric Profile Analysis

Table 5.1. highlights the athlete characteristics, BM loss requirements and anthropometric profiles for each participant, both individually and collectively. There was a significant main effect of age ($p = 0.02$), stature ($p = 0.002$) and body mass ($p < 0.001$) between athletes in the differing weight categories. Differences in age were present between the Fly athletes, who were 5 years younger than the Feather (95% CI = -8.42 to -0.05, ES = 2.24, $p = 0.04$) and Welter athletes (95% CI = -8.98 to -0.17, ES = 1.71, $p = 0.04$) and also stature, where the Welter athletes were 7-9 cm taller than the Fly (95% CI = -15.0 to -3.61, ES = 2.36, $p = 0.002$) and Feather (95% CI = -12.70 to -0.92, ES = 2.54, $p = 0.02$) athletes. BM differed by 10-16 kg across all athlete categories ($p < 0.001$).

There was no significant main effect in the amount of BM loss required between WT categories ($p = 0.23$). However, there were significant differences in the amount of BM loss required for the athletes respective OG weight categories ($p = 0.02$). Athletes in the Fly category needed to lose 5 kg less than the Feather athletes (95% CI = 5.67 to 1.69, ES = 1.86, $p = 0.01$) and despite no significant difference, yet moderate effect sizes (ES = 0.94, $p = 0.28$), 2.5 kg less than the Welter athletes. This was also the case between Feather and Welter athletes (ES = 1.16, $p = 0.59$). Considering athletes collectively, there were differences (95% CI = -4.79 to -1.45, ES = 1.24, $p = 0.001$) between the BM loss requirement to meet their elected WT and OG weight categories. However, examining weight categories individually, this was only highlighted in the Feather athletes who needed to lose an additional 5 kg of BM (95% CI = -7.57 to -2.43, ES = 2.49, $p = 0.004$). There were no differences in the Fly (ES = 0.43, $p = 0.42$) and Welter (ES = 2.14, $p = 0.07$) athletes, despite needing to lose an additional 1.0 and 3.9 kg of BM for their OG categories, respectively.

Table 5.1. *Comparative characteristics, BM loss requirements and anthropometric profiles of male international level Taekwondo athletes. Athletes are sectioned into their respective OG weight categories with individual regular WT weight category information in parentheses.*

CATEGORY	AGE	STATURE	BODY MASS	TIME TO WI	WT	OG	DXA WB-BMC/D	DXA WB-LM	DXA WB-FM	DXA-FM	$\sum_{8SKf}$
FLY -58 kg	**(Years)** ✱	**(Cm)** ✱	**(Kg)** ✱	**(Days)**	**(Kg)**	**(Kg)** ✱	**(Kg) [Z-Score]** ✱	**(Kg)** ✱	**(Kg)** ✱	**(%)**	**(Mm)**
1 (Fin -54 kg) - Black	*17*	*169.5*	*53.8*	*1*	*0.0*	*0.0*	*2.03 [0.5]*	*42.6*	*5.1*	*10.3*	*43.2*
2 (Fin -54 kg) - Caucasian	*17*	*183.5*	*57.2*	*4*	*3.2*$^{!}$	*0.0*	*2.16 [0.0]*	*46.6*	*4.9*	*9.3*	*36.3*
3 (Fly -58 kg) - Caucasian	*20*	*179.0*	*58.9*	*2*	*0.9*	*0.9*	*2.25 [0.2]*	*48.6*	*4.7*	*8.4*	*36.2*
4 (Fly -58 kg) - Caucasian	*17*	*182.5*	*59.2*	*4*	*1.2*	*1.2*	*2.03 [0.0]*	*49.1*	*4.7*	*8.4*	*35.7*
5 (Fly -58 kg) - Black	*17*	*180.4*	*59.6*	*4*	*1.6*	*1.6*	*2.52 [0.5]*	*49.2*	*5.0*	*9.3*	*40.4*
6 (Bantam -63 kg) - Black	*17*	*178.5*	*64.9*	*2*	*1.9*	*6.9*$^{!}$	*2.45 [1.5]*	*51.8*	*7.2*	*12.2*	*60.3*
7 (Bantam -63 kg) - Caucasian	*17*	*182.0*	*65.0*	*1*	*2.0*	*7.0*$^{!}$	*2.43 [1.3]*	*52.8*	*7.1*	*11.4*	*57.3*
MEAN ± SD	**17 ± 1^{bc}**	**179.3 ± 4.7**	**59.8 ± 4.0^{bc}**	**3 ± 1**	**1.5 ± 1.0**	**2.5 ± 3.1^{b}**	**2.27 ± 0.2^{bc}**	**48.7 ± 3.4^{bc}**	**5.5 ± 1.1^{bc}**	**9.9 ± 1.5**	**44.2 ± 10.4**
FEATHER -68 kg											
8 (Feather -68 kg) - Black	*17*	*180.0*	*72.3*	*4*	*4.3*$^{!}$	*4.3*$^{!}$	*2.58 [1.6]*	*60.7*	*5.9*	*8.7*	*42.9*
9 (Light -74 kg) - Caucasian	*21*	*185.0*	*75.3*	*4*	*1.3*	*7.3*$^{!}$	*2.89 [1.6]*	*62.7*	*6.0*	*8.4*	*39.6*
10 (Light -74 kg) - Black	*22*	*180.5*	*74.4*	*4*	*0.4*	*6.4*$^{!}$	*2.98 [2.7]*	*59.7*	*7.7*	*10.8*	*50.8*
11 (Light -74 kg) - Caucasian	*21*	*183.5*	*75.1*	*2*	*1.1*	*7.1*$^{!}$	*2.71 [1.3]*	*61.3*	*7.8*	*10.8*	*54.2*
12 (Light -74 kg) - Black	*27*	*179.0*	*78.5*	*4*	*4.5*$^{!}$	*10.5*$^{!}$	*2.81 [1.3]*	*65.0*	*7.5*	*9.9*	*43.9*
13 (Light -74 kg) - Caucasian	*22*	*183.0*	*77.2*	*4*	*3.2*	*9.2*$^{!}$	*2.99 [1.7]*	*64.6*	*8.2*	*10.9*	*52.5*
MEAN ± SD	**22 ± 3**	**181.8 ± 2.3**	**75.5 ± 2.2^{ac}**	**4 ± 1**	**2.5 ± 1.8**	**7.5 ± 2.2+**	**2.83 ± 0.2^{ac}**	**62.3 ± 2.2^{ac}**	**7.2 ± 0.9**	**9.9 ± 1.1**	**47.3 ± 6.0**
WELTER -80 kg											
14 (Welter -80 kg) - Caucasian	*18*	*189.5*	*83.1*	*4*	*3.1*	*3.1*	*2.90 [1.6]*	*67.5*	*9.0*	*11.3*	*63.0*
15 (Welter -80 kg) - Caucasian	*28*	*187.3*	*82.4*	*4*	*2.4*	*2.4*	*3.01 [1.9]*	*67.0*	*9.0*	*11.4*	*61.9*
16 (Middle -87 kg) - Caucasian	*21*	*187.0*	*86.8*	*2*	*0.0*	*6.8*$^{!}$	*3.36 [4.4]*	*69.8*	*9.4*	*11.3*	*61.2*
17 (Middle -87 kg) - Black	*23*	*186.0*	*85.7*	*3*	*0.0*	*5.7*$^{!}$	*3.38 [1.5]*	*72.0*	*7.2*	*8.7*	*42.7*
18 (Middle -87 kg) - Black	*20*	*193.4*	*86.9*	*4*	*0.0*	*6.9*$^{!}$	*3.76 [2.5]*	*71.5*	*9.0*	*10.6*	*51.7*
MEAN ± SD	**22 ± 4**	**188.6 ± 3^{ab}**	**85.0 ± 2.1**	**3 ± 1**	**1.1 ± 1.5**	**5.0 ± 2.1**	**3.28 ± 0.3**	**69.6 ± 2.2**	**8.7 ± 0.9**	**10.7 ± 1.1**	**56.1 ± 8.8**
ALL CATEGORIES MEAN ± SD	**20 ± 4**	**182.8 ± 5.2**	**72.0 ± 11.0**	**3 ± 1**	**1.6 ± 1.6**	**4.6 ± 3.8+**	**1.5 ± 1.1**	**53.6 ± 18.6**	**6.4 ± 2.3**	**9.3 ± 2.8**	**48.6 ± 8.7**

✱*significant main effect of between weight category differences $p < 0.05$. ^{a} denotes significant difference to Fly (-58 kg) weight division $p < 0.05$. ^{b} denotes significant difference to Feather (-68 kg) weight division $p < 0.05$. ^{c} denotes significant difference to Welter (-80 kg) weight division $p < 0.05$. +significant difference between amount of body mass loss required for respective WT and OG weight categories $p < 0.05$. $^{!}$denotes athlete is above 5% BM re-weigh in allowance.*

Concomitantly with BM values, there was a significant main effect observed when comparing DXA derived whole body BMC (DXA WB-BMC), LM (DXA WB-LM) and FM (DXA WB-FM) between athletes in the differing weight categories ($p < 0.001$). Fly athletes displayed WB-BMC values 0.5 kg less than the Feather (95% CI = −0.91 to -0.21, ES = 2.80, $p = 0.002$) and 1.0 kg less than the Welter (95% CI = −1.39 to -0.64, ES = 3.96, $p < 0.001$) athletes, whereas the Feather athletes were 0.5 kg lower than the Welter (95% CI = −0.84 to -0.07, ES = 1.77, $p = 0.02$) athletes. For measures of WB-LM, Fly athletes presented values 13.6 kg lower than the Feather (95% CI = −13.70 to 1.51, ES = 4.75, $p < 0.001$) and 20.9 kg lower than the Welter athletes (95% CI = −20.90 to 1.59, ES = 7.30, $p < 0.001$). Interestingly, Feather athletes presented values that were only 7.3 kg lower than Welter athletes (95% CI = −7.21 to 1.65, ES = 3.32, $p = 0.002$). Finally, for measures of WB-FM, Fly athletes were 1.7 kg lower than the Feather (95% CI = −1.65 to 0.55, ES = 1.69, $p = 0.02$) and 3.2 kg lower than the Welter athletes (95% CI = −3.16 to 0.58, ES = 3.18, $p < 0.001$). There was a mean 1.5 kg difference between the Feather and Welter athletes, yet this was non-significant despite a large effect size (ES = 1.67, $p = 0.07$). There were no differences in DXA-FM% ($p = 0.54$) between athletes in the differing weight categories with an average of 9.3 ± 2.8%.

With values varying by 3.1-11.9 mm across weight categories, there was no significant main effect of $\sum_{8SKf}$ ($p = 0.09$) despite a large effect size (ES = 1.24) between the Fly and Welter athletes. There was a strong correlative association apparent between $\sum_{8SKf}$ and DXA-FM% ($r = 0.92$, 95% CI = 0.78 to 0.97, $p < 0.001$), which was also present when athletes were distributed into either Black ($r = 0.88$, 95% CI = 0.46 to 0.98, $p = 0.004$) or Caucasian ($r = 0.96$, 95% CI = 0.85 to 0.99, $p < 0.001$) ethnicities. Table 5.2 highlights each individual regional (torso and upper/lower limbs) SKf site association with DXA-FM%, demonstrating all locations were positively correlated. Individual SKf site r values and 95% CI varied with the highest correlations between DXA-FM% positioned in the torso (iliac crest, supraspinale, abdomen) and lower limbs (anterior thigh, medial calf).

Table 5.2. *The relationship (r) and 95% CI between DXA-FM% and individual SKf sites in male international level Taekwondo athletes prior to competition.*

SKf SITE	DXA-FM% (r)	95% CI
Bicep	*0.68 (p = 0.002)*	*0.31-0.87*
Tricep	*0.67 (p = 0.003)*	*0.30-0.80*
Subscapular	*0.66 (p = 0.003)*	*0.28-0.86*
Iliac Crest	*0.76 (p < 0.001)*	*0.46-0.91*
Supraspinale	*0.80 (p < 0.001)*	*0.53-0.92*
Abdomen	*0.77 (p < 0.001)*	*0.48-0.91*
Anterior Thigh	*0.77 (p < 0.001)*	*0.47-0.91*
Medial Calf	*0.71 (p = 0.001)*	*0.35-0.88*

5.3.2. Comparative and Pairwise Regional Body Composition Analysis

Regional differences in LM and FM between athlete weight categories are presented in Table 5.3.

Dominant and Non Dominant Arm Lean and Fat Masses

There were small differences between the dominant (DA-LM) and non-dominant (NDA-LM) arm LM of athletes in the Fly (95% CI = 0.08 to 0.39, ES = 0.32, $p = 0.01$), Feather (95% CI = 0.03 to 0.27, ES = 0.47, $p = 0.03$) and Welter (95% CI = 0.00 to 0.15, ES = 0.40, $p = 0.04$) categories. However, this was not the case for the dominant (DA-FM) or non-dominant (NDA-FM) arm FM between athletes of all the respective categories.

There was a significant main effect of DA-LM between athletes in the differing weight categories ($p < 0.001$), where Fly athletes had 1.1 kg and 1.5 kg less mass than Feather (95% CI = −1.10 to 0.20, ES = 2.59, $p < 0.001$) and Welter (95% CI = -1.53 to 0.21, ES = 7.44, $p < 0.001$) athletes, respectively. Differences between NDA-LM, were also apparent between weight categories ($p < 0.001$). Fly athletes had 1.1 kg and 1.7 kg less mass than Feather (95% CI = −1.10 to 0.16, ES = 3.34, $p < 0.001$) and Welter (95% CI = −1.69 to 0.16, ES = 13.26, $p < 0.001$) athletes, whereas Feather athletes had 0.6 kg less mass than Welter athletes (95% CI = −0.60 to 0.17, ES = 1.79, $p = 0.009$). There was also a main effect of DA-FM across all athletes' weight categories ($p < 0.001$). Fly athletes had 0.1 kg and 0.3 kg less mass than Feather (95% CI = −0.13 to 0.04, ES = 2.35, p = 0.008) and Welter (95% CI = −0.26 to 0.04, ES = 3.40, p < 0.001) athletes, whereas Feather athletes had 0.1 kg less mass than Welter athletes (95% CI = −0.13 to 0.04, ES = 1.79, p = 0.02). Differences were also present for NDA-FM (p = 0.004), where Fly athletes had 0.1 kg and 0.2 kg less mass than Feather (95% CI = −0.11 to 0.40, ES = 1.51, p = 0.04) and Welter (95% CI = −0.26 to 0.04, ES = 4.16, p < 0.001) athletes, respectively. Despite a 0.1 kg difference in NDA-FM between the Feather and Welter athletes, this was none significant regardless of a large effect size (ES = 1.57, p = 0.82).

Trunk Lean and Fat Masses

There were significant main effects between trunk lean (TRUNK-LM) (p < 0.001) and fat (TRUNK-FM) (p = 0.001) masses. Fly athletes had 6.7 kg and 10.8 kg less TRUNK-LM than Feather (95% CI = −6.67 to 0.96, ES = 3.56, p < 0.001) and Welter (95% CI = −10.77 to 1.01, ES = 6.07, p < 0.001) athletes, whereas Feather athletes had 4.1 kg less TRUNK-LM than Welter athletes (95% CI = −4.10 to 1.04, ES = 1.04, p = 0.004). There were only significant differences in TRUNK-FM between Fly athletes, who had 0.9 kg and 1.4 kg less mass than Feather (95% CI = −0.87 to 0.29, ES = 2.11, p = 0.03) and Welter (95% CI = −1.37 to 0.30, ES = 2.25, p = 0.001) athletes.

Table 5.3. *A comparison of DXA derived regional LM and FM between male international level Taekwondo athletes in OG weight divisions.*

	FLY -58 kg (n = 7)	**FEATHER -68 kg (n = 6)**	**WELTER -80 kg (n = 5)**
DA-LM ✱	*2.90 ± 0.22*^{bc}+	*4.00 ± 0.56* +	*4.43 ± 0.19* +
NDA-LM ✱	*2.67 ± 0.10*^{bc}	*3.76 ± 0.45*^{ac}	*4.36 ± 0.15*
DA-FM ✱	*0.35 ± 0.06*^{bc}	*0.48 ± 0.05*^{ac}	*0.61 ± 0.09*
NDA-FM ✱	*0.35 ± 0.05*^{bc}	*0.46 ± 0.09*	*0.58 ± 0.06*
TRUNK-LM ✱	*24.63 ± 2.27*^{bc}	*31.29 ± 1.36*^{ac}	*35.39 ± 1.06*
TRUNK-FM	*2.21 ± 0.46*^{bc}	*3.08 ± 0.36*	*3.58 ± 0.73*
DL-LM ✱	*9.31 ± 0.73*^{bc}	*11.70 ± 0.76*	*12.73 ± 1.13*
NDL-LM ✱	*9.15 ± 0.73*^{bc}	*11.59 ± 0.57*	*12.64 ± 1.13*
DL-FM ✱	*1.34 ± 0.41*^{c}	*1.61 ± 0.32*	*2.03 ± 0.27*
NDL-FM ✱	*1.29 ± 0.30*^{c}	*1.56 ± 0.27*	*1.97 ± 0.25*

✱*significant main effect of between weight category differences* $p < 0.05$. ^{a} *denotes significant difference to Fly (-58 kg) weight division* $p < 0.05$. ^{b} *denotes significant difference to Feather (-68 kg) weight division* $p < 0.05$. ^{c} *denotes significant difference to Welter (-80 kg) weight division* $p < 0.05$. *+significant difference between dominant and non-dominant limbs* $p < 0.05$.

Dominant and Non Dominant Leg Lean and Fat Masses

There were no differences between the dominant (DL-LM) and non-dominant (NDL-LM) leg LM, or the dominant (DL-FM) or non-dominant (NDL-FM) leg FM between athletes of all the respective weight categories, which was additionally confirmed by trivial to small effect sizes.

There was a main effect of DL-LM ($p < 0.001$), where Fly athletes had 2.4 kg and 3.4 kg less mass than Feather (95% CI = −2.39 to 0.48, ES = 3.21, $p < 0.001$) and Welter (95% CI = -3.43 to 0.50, ES = 3.60, $p < 0.001$) athletes, respectively. There was also a difference in NDL-LM between athletes across weight categories ($p < 0.001$). Fly athletes also had 2.4 kg and 3.5 kg less mass than Feather (95% CI = −2.44 to 0.45, ES = 3.73, $p < 0.001$) and Welter (95% CI = −3.49 to 0.48, ES = 3.67, $p < 0.001$) athletes. There was a significant main effect of DL-FM ($p = 0.02$), where Fly athletes had 0.7 kg less mass than Welter (95% CI = −0.69 to 0.20, ES = −1.99, $p = 0.01$) athletes. Despite no significance in DL-FM between the Feather and Welter athletes there was a large effect size (ES = 1.42) due to a 0.4 kg difference in mass. Main effects were also present for NDL-FM ($p = 0.003$). Fly athletes also had 0.7 kg less mass than Welter athletes (95% CI = −0.68 to

0.16, ES = 2.46, $p = 0.002$) and again despite no significance there was a large effect size (ES = 1.58) given a 0.4 kg mass difference between the Feather and Welter athletes.

5.3.3. Body Composition Method Comparison Regression Analyses

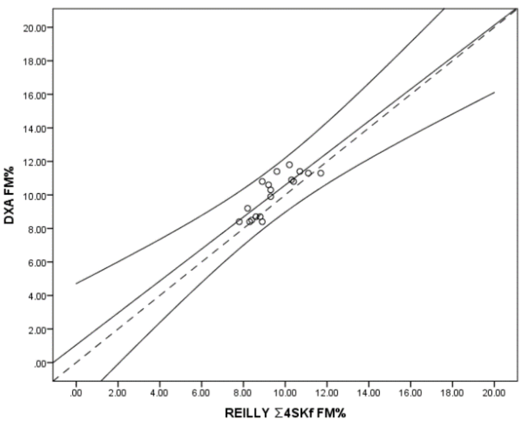
Utilising least squares regression analysis, the slopes, intercepts and the SEE together with 95% PI for comparison of body composition methods are presented in Table 5.4 and Figure 5.1 A-J. The random error associated with each $\sum_{SKf}$ FM% prediction equation were relatively similar, with the smallest value being 0.65 (Withers $\sum_{7SKf}$) and the largest being 0.95 (J&P Σ_{3SKf} & Brozek). The 95% PI for each equation were also similar in magnitude with the highest being 2.03 (J&P Σ_{3SKf} & Brozek) and lowest 1.39 (Withers $\sum_{7SKf}$).

Estimates of FM% using both the equations of Reilly $\sum_{4SKf}$ (Figure 1-A) and Eston Σ_{2SKf} (Figure 1-B), showed the least amount of both fixed bias with the intercept being closest to zero and proportional bias with the slope of the respective lines being closest to one. The slopes and positions of the regression lines for the other eight $\sum_{SKf}$ predication equations in both Table 5.4 and Figures 5.1 C-J, provide strong evidence for the presence of both fixed and proportional biases, that result in conflicting values of FM% compared to DXA. There was an unacceptable level of fixed bias, ranging from the highest 7.19 (J&P Σ_{3SKf} & Siri) to the lowest 3.60 (D&W Σ_{4SKf} & Brozek) and also an unacceptable level of proportional bias, ranging from the lowest 0.53 (J&P Σ_{3SKf} & Brozek) to the highest 0.73 (Withers$\sum_{7SKf}$).

Table 5.4. *Least Squares regression analysis (r) of the slopes, intercepts, SEE and the mean of the 95% PI of DXA-FM% vs. FM% predicted from $\sum SKf$ equations in male international level Taekwondo athletes.*

METHOD	MEAN ± SD	SLOPE	INTERCEPT	SEE	r	MEAN 95% PI #
DXA	9.3 ± 2.8	-	-	-	-	-
Eston et al. (2005) − Σ_{2SKf}	10.0 ± 1.2	0.91 (0.62-1.21)	0.94 (-2.05-3.91)	0.68	0.85* (0.64-0.94)	1.60 (3.19)
D&W − Σ_{4SKf} (1974) & Brozek (1963)	9.7 ± 1.5	0.66 (0.41-0.92)	3.60 (1.12-6.08)	0.76	0.81* (0.56-0.93)	1.63 (3.26)
Reilly et al. (2009) – $\sum_{4SKf}$	9.3 ± 0.9	0.95 (0.61-1.30)	1.05 (-2.26-4.36)	0.74	0.82* (0.58-0.93)	1.54 (3.08)
D&W − Σ_{4SKf} (1974) & Siri (1961)	9.1 ± 1.7	0.61 (0.37-0.84)	4.50 (2.31-6.68)	0.77	0.81* (0.55-0.93)	1.65 (3.29)
Withers et al. (1987) – $\sum_{7SKf}$	7.7 ± 1.3	0.73 (0.51-0.96)	4.27 (2.47-6.07)	0.65	0.87* (0.67-0.95)	1.39 (2.78)
Eston et al. (2005) – Σ_{6SKf}	6.7 ± 1.4	0.66 (0.32-0.99)	5.62 (3.31-7.93)	0.90	0.72* (0.38-0.89)	1.89 (3.77)
J&P – Σ_{7SKf} (1978) & Brozek (1963)	5.8 ± 1.2	0.72 (0.47-0.99)	5.79 (4.26-7.33)	0.72	0.83* (0.60-0.94)	1.64 (3.28)
J&P – Σ_{3SKf} (1978) & Brozek (1963)	5.6 ± 1.4	0.53 (0.23-0.83)	6.86 (4.98-8.75)	0.95	0.68* (0.31-0.87)	2.03 (4.05)
J&P – Σ_{7SKf} (1978) & Siri (1961)	4.9 ± 1.3	0.67 (0.42-0.92)	6.69 (5.37-8.00)	0.75	0.81* (0.56-0.93)	1.69 (3.38)
J&P – Σ_{3SKf} (1978) & Siri (1961)	4.7 ± 1.5	0.58 (0.36-0.79)	7.19 (6.07-8.31)	0.74	0.82* (0.57-0.93)	1.64 (3.28)

✱significantly correlated with DXA. # PI ranges may be calculated by multiplying the 95 % PI interval by 2 (Ranges are in parentheses).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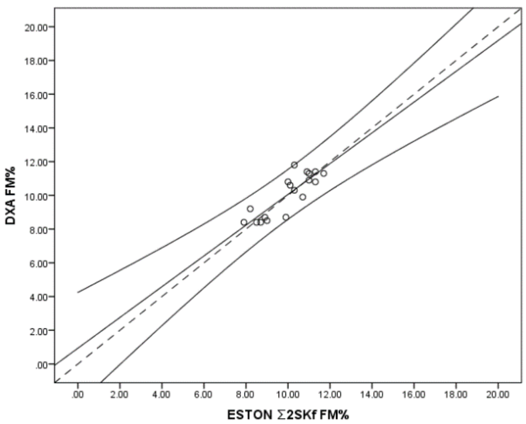
A.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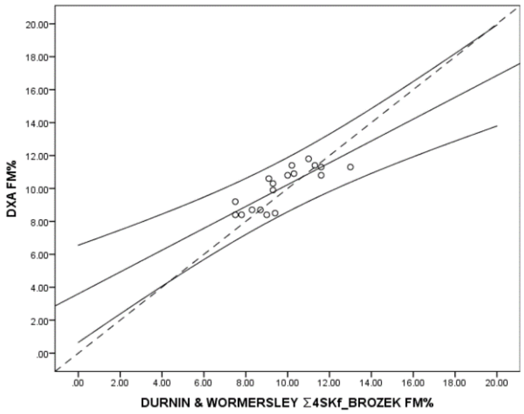
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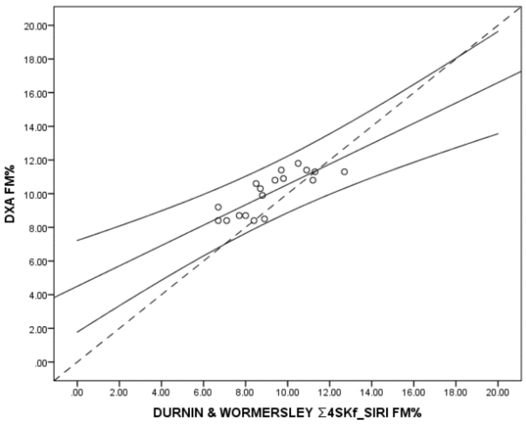
DURNIN & WORMERSLEY Σ4SKf_BROZEK FM%

C.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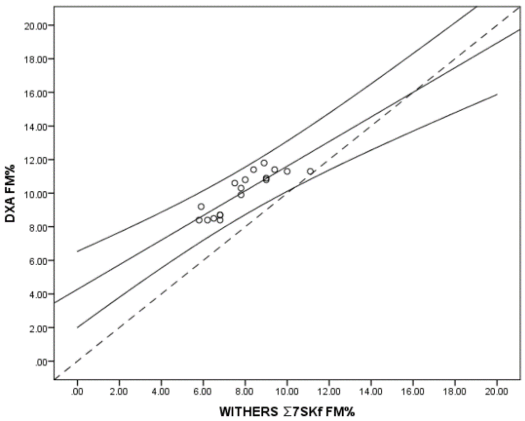
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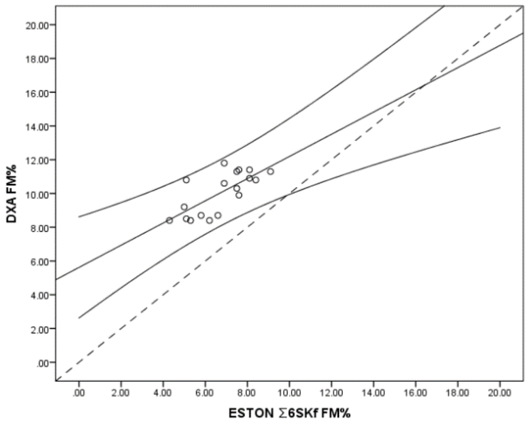
E.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F.

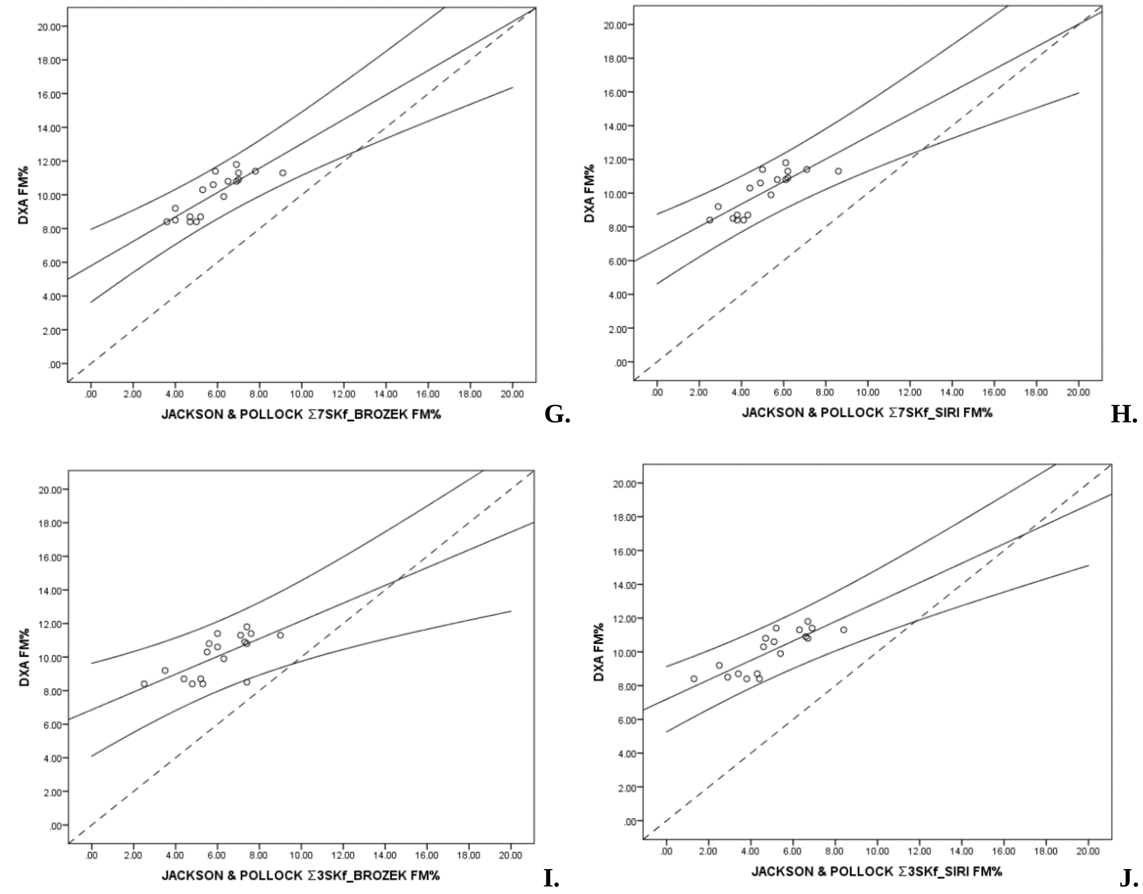


Figure 5.1. *Least squares regression plots of DXA-FM % vs.* $\sum_{SKf}$ *FM% prediction equations in male international level Taekwondo athletes.*

Plots indicate line of Unity (broken line), line of regression and 95% PI (solid outer lines).

5.4. Discussion

The main aim of this study was to evaluate the body composition indices of international standard Taekwondo athletes utilising laboratory and field based methods and absolute BM losses when required to make weight for OG or WT categories. As highlighted in Table 5.1. 4 days up to 24 hours prior to weighing in for their respective WT categories, collectively these athletes needed to lose an additional range of 0.0 to 4.5 kg of BM. Considering the new re-weigh in ruling, only 3 (17%) of the athlete group are above the 5% BM restriction for their elected WT weight category, exceeding this by a range of 0.9 to 1.3%. Alarmingly, if these athletes were required to weigh in for their respective OG weight category, the range of BM loss increases from 0.0 to 10.5 kg. Again, acknowledging the new 5% BM re-weigh in ruling, 11 (61%) of the athlete group (including 100% in the -68 kg Feather category) would be above this limit by a range of 1.3 to 10.4%. Highlighting individual cases, athletes 6, 7, 10, 11, 13, 16 and 18 could potentially attain additional BM losses via FM, through a prolonged period of energetic deficit. However despite this, these athletes would still require exacerbated losses beyond 5% BM, needing to implement acute dehydration or losses in LM due to reaching a 6% threshold of essential FM (see section 2.7). Emphasising another specific case, athlete 12 would require a 9.5% acute loss of BM beyond what could be achieved via manipulations to their BM tissues.

There have been a number of position stands and research articles encouraging combat sport athletes not to exceed these recommended thresholds of FM and limit dehydration to <5% of BM (Franchini et al., 2012; Oppliger et al., 1996; Reale et al., 2017b), particularly due to a number of deaths in numerous combat sport disciplines over the past three decades (see section 2.6). Numerous studies examining A/RWL techniques, including energetic restriction and dehydration, have highlighted the negative impact on both performance and psychological, physiological, endocrine and immune functions in a range of combat sports (as highlighted in section 2.6) highlighting a potential for LEA potentially leading to RED-S consequences. Independent of this, it is clear that to attain their elected OG weight category, a large proportion of the athlete group in this study would need to accommodate a chronic period of LEA and acute use of extreme dehydration techniques beyond a threshold of 5% BM loss, in violation of the new ruling.

This study is the first to characterise both the whole body and regional indices of BMC/D, LM, and FM/% utilising DXA in male international Taekwondo athletes, across weight categories and directly prior to a competition weigh in. As demonstrated in Table 5.1. BMC, LM and FM differed between all athlete categories. Interestingly, all athletes displayed positive BMD based on individual Z-Scores ranging from 0.0 to 4.4. These results may potentially support the idea, that the negative associations of low BMD are offset by the osteogenic stimulus provided by the athletes training activities (Seo et al., 2015) although further evidence is required to substantiate this. Another interesting observation, highlights the BMD of the differing athlete groups increases from the lower to higher weight categories, in support of research showing that combat sport training is favourably associated with increases in BMD concurrent with age (Ito et al., 2017; Nasri et al., 2015). It is unsurprising that whole body and regional indices of LM and FM vary between groups, given the differences in BM. However, the Feather and Welter category athletes display values which are in stark contrast to the Fly category athletes, potentially being attributed to differences in age and therefore maturation status (Malina & Geithner, 2011). Where most of the athletes are at a lower tier of FM as they approach the competition weigh in, again the Fly athletes are lower than their older counterparts and the FM% between the athlete categories is not different in disagreement with athletes from other sports (Milsom et al., 2015) but not uncharacteristic of this age demographic when training (Malina & Geithner, 2011). Closer examination of the dominant and non-dominant limbs of this athlete group in Table 5.3, indicate that both the indices of LM and FM in the leg region are in balance across all categories, whereas LM is higher in the dominant arm. Yet again, this is unsurprising given the technical and tactical requirements of the sport where punching actions are generally only performed on the dominant arm to the opponents trunk and kicking actions are required in attack and counter motions to the trunk and head, asymmetrically with both limbs (Falco et al., 2009; Kim & Kim, 2010).

Due to the aforementioned BM loss requirements as being a key component in the measurement of EA status, the ability to examine body composition accurately based on indices of LM and FM is therefore vital for this athlete group. As DXA allows both whole body and regional assessments of body composition tissues, it could be regarded as an ideal tool to achieve this aim, however, its use can be contentious (see section 2.2.1). As such a high frequency of DXA utilisation cannot always be employed, the use of Σ_{SKf} across varying upper and lower sites, can be implemented more periodically with a higher degree of measurement accuracy than with the addition of FM% predication equations (Johnston, 1982). In support of Reilly et al. (1996), this study demonstrates the importance of lower limb individual SKf measurement sites, given the strong correlations highlighted in Table 5.2. The assessment of body composition utilising Σ_{8SKf} in this study, did have strong associations with DXA-FM% independent of ethnicity, however despite this, it only gives a limited view of the adjustments to both LM and FM tissues particularly in varying body regions. Evidently, a conjoined approach of utilising both DXA and Σ_{SKf} methods would aid in making calculated and informed judgements about an athlete’s potential to reduce BM and achieve a specific weight category. The findings of this study indicated that of the ten Σ_{SKf} equations examined, eight of these provided unreliable estimations of FM%. Assessed via least squares regression, only the Reilly $\sum_{4SKf}$ and Eston Σ_{2SKf} equations provide measurement data, which can be deemed as both valid and accurate in tandem with DXA as the criterion method (see Figure 5.1 A & B). With both of these equations being generated from DXA derived models, conducted in athletic populations and including lower limb measurement sites, it is foreseeable as to why they fit the participant population within this study favourably.

5.5. Conclusion

This study has highlighted for the first time the requirement of BM loss for international standard Taekwondo athletes competing in two differing WT and OG weight categories. Where the losses for the WT categories are relatively small preceding the competition weigh in, the magnitudes of requirement for the OG categories are concernedly large (in agreement with Chapter 3). This highlights the necessity for these athletes to engage in BM loss practices, which may be harmful to both health and performance and also the increased potential to violate the 5% BM re-allowance ruling. Also for the first time, this study provides both whole body and regional indices of body composition in this athlete population within close proximity of a competition weigh in, highlighting differences between categories and the distribution of BMC/D, LM and FM-%. The BMD Z-Score values of this athlete group were positive, highlighting no apparent negative associations of BM loss, although further work is required examining longitudinal effects. Given that BM differs between categories, it is understandable that concurrently, so do values of LM and FM based on age. In this study only two of the ten $\sum_{SKf}$ FM% equations were judged to have acceptable accuracy based on the same measurement obtained via DXA. To that regard the other eight $\sum_{SKf}$ are not recommended for use in this athlete population, especially given they are often habitually employed in both the applied and research arenas, highlighting the need to approach any studies which have been conducted utilising these measures with caution.

CHAPTER 6.

Comparisons of Perceptual, Physiological and Energy Expenditure Measurement During Simulated Taekwondo Competition Bouts: Influence of Differing Activity:Recovery Ratios.

6.1. Introduction

Chapter 2 (section 2.6) alongside Chapters 3 and 4 have highlighted international standard Taekwondo athletes engage in making weight practices to reduce BM for competition. Additionally, these Chapters have also elucidated that Taekwondo athletes particularly engage in chronic BM loss via reductions in EI and increases in AEE. These practices may lead to periods of LEA, increasing the potential for negative RED-S consequences on both health and performance. For the assessment of EA status, practitioners need to examine the EI and AEE alongside measurements of FFM. Chapter 5 has provided a practical solution for field based examination of body composition, however, understanding the energetic demands of sport specific activities is vital in formulating BM loss strategies which are periodised to limit the negative associations of LEA leading to RED-S. Numerous studies (see sections 2.4.3 and 2.8.3) have demonstrated the challenges of studying metabolic and physiological responses during both Taekwondo training and competitive bouts and to date, field based measurements of AEE have not yet been established.

Portable actigraphy utilising both combined HR and accelerometry presents an interesting possibility for the measurement of AEE in Taekwondo training and competition activities. The Actiheart (CamNtech Ltd. Papworth, UK) is a combined HR and accelerometery unit that is designed to be worn on the chest, which combats the limitations of most other potable actigraphy monitors worn at the hip, which do not take into account upper body movements. Brage et al. (2005) provide an in depth description of the Actiheart specifications and functions for further information. Combined HR and accelerometry data generated by the Actiheart, can be used to calculate AEE via a branched chain equation model as the sensitivity of the HR sample increases with the amount of activity movement detected. The branched chain equation model employed by the Actiheart to calculate AEE, uses group calibration regressions which have been derived from walking and running based treadmill studies (Brage et al., 2004; Brage et al., 2007) and has previously been utilised in investigations on athletic demographics (Nichols et al., 2010; Wilson et al., 2013).

Therefore, the aims of this study were twofold. Firstly, to create a range of ecologically valid simulated Taekwondo competition pad-work (STCP-W) protocols with varying activity:recovery ratios. Secondly, to assess the validity and accuracy of the Actiheart for measurements of both HR and AEE versus both a Polar commercial HR monitor (CHRM) and indirect calorimetry, acting as the criterion methods during each STCP-W protocol.

6.2. Methods

The experiment incorporated a repeated-measures, counter-balanced, Latin squares research design. Participants visited the laboratory on three separate occasions with >48 hours between trials. At visits one, two and three and in a randomised order established by computerised software, participants completed a STCP-W protocol across three separate conditions of activity:recovery ratio, to monitor different responses in both perceptual, physiological and metabolic measurements. Participants were not conducting any BM loss practices and 24 hours pre testing were requested to refrain from any alcohol, caffeine and excessive exercise so not to confound measured variables. Prior to all visits, participants were additionally requested to fast for a 12 hour period, hydration intake was controlled (7 $ml \cdot kg \cdot BM^{-1}$) derived from pre exercise ACSM guidelines (Maughan & Shirreffs, 2008, 2010; Sawka et al., 2007) and were familiarised with the protocol. All tests for each participant were completed at the same time of day, between 9.00am and 3.00pm to limit any diurnal variation (Thun et al., 2015) and temperature was fixed at 21°C with relative humidity between 40-45%.

6.2.1. Participants

Eight male international standard Taekwondo athletes (20 ± 3 years old, 73.2 ± 15.3 kg, 182.1 ± 6.5 cm) were selected on the basis of the following inclusion criteria: (a.) >17 and <35 years of age, (b.) minimum of 1st Dan grade and (c.) >3 years international competition experience. All participants had no previous incidence of musculoskeletal injury within six months of the study and/or any history of previous medical conditions, which would render them unsuitable for participation. There were two participants per OG weight category (-58 Fly, -68 Feather, -80 Welter and +80 Heavy). The study was conducted in accordance with the Liverpool John Moores University research ethics committee approval, all participants were informed of the test procedures, potential risks and written informed consent was obtained.

6.2.2. Procedures

STCP-W Protocols

Prior to the main trials a fifteen minute warm-up protocol was completed utilising the RAMP (Raise/Activate/Mobilise/Potentiate) method (Jeffreys, 2007) (see Appendix 3). HR was assessed throughout the warm-up protocol to monitor no elevation above 50% of predicted HR_{max}. The STCP-W protocol was set at the same pattern of activity as within a typical Taekwondo bout (3 x 2 min rounds/1 min rest period). Three separate conditions were designed to test the ecological validity of each STCP-W protocol across a range of differing activity:recovery ratios based on a number of Taekwondo time motion analysis studies (Bridge et al., 2011; Falco et al., 2012; Santos et al., 2011; Tornello et al., 2013). STCP-W 1:7 (light intensity), STCP-W 1:5 (competition intensity) and STCP-W 1:2 (hard intensity) protocols, utilised varying kicking and movement actions within each 2 minute round, where intervals were based on 2 seconds of kicking activity, which is demonstrated to be the average engagement time in a competitive Taekwondo bout (see section 2.6.1). As used in the warm-up, the intervals were completed on a set of Taekwondo kicking pads (Adidas, Jewoo Sports Co. Seoul, Korea), which are regarded as an ecologically valid training tool (Bridge et al., 2007). Activity commenced on the command of three possible kicking combinations controlled by audio signal software (automated in Cubase 5, Steinberg, Hamburg, Germany - edited to the millisecond), to elicit the same choice response variations as found in both training and competition. The kicking combinations included the attack and counter variations of the turning kick (dollyo chagi) and fast/front leg kick (*bandal chagi*), which have also been highlighted as the most common techniques utilised in Taekwondo bouts (Bridge et al., 2013; Falco et al., 2012; Santos et al., 2011).

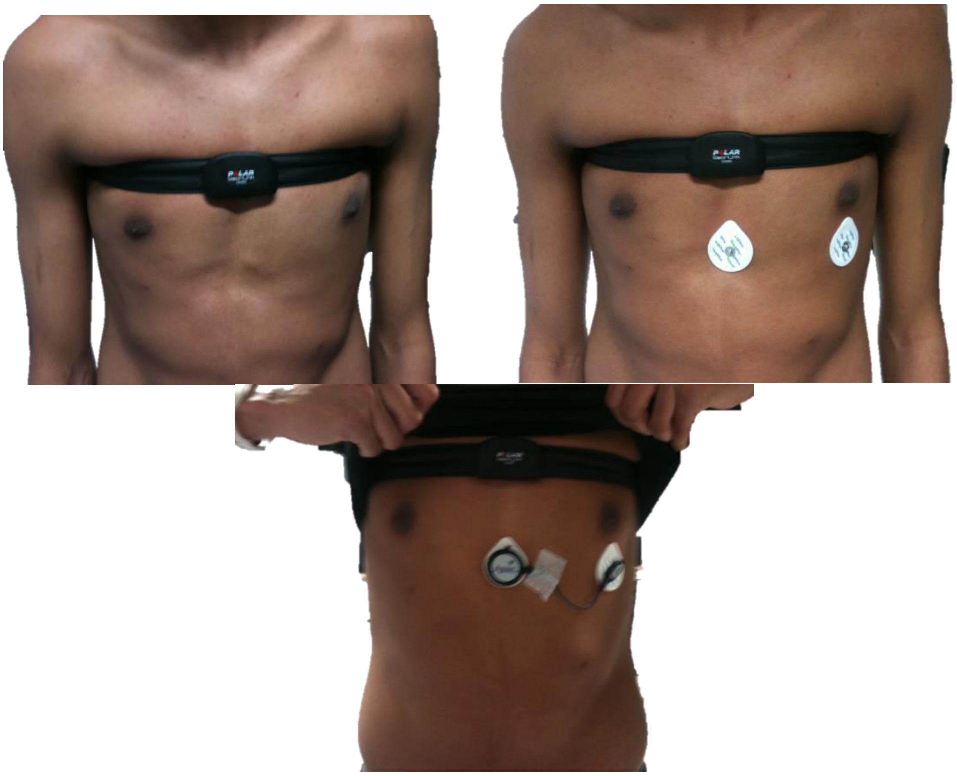


Figure 6.1. *Attachment of the Polar RS400 CHRM and Actiheart prior to the commencement of each STCP-W protocol.*

Perceptual and Physiological Measurements

Post warm-up and pre protocol, the Actiheart unit was attached to the participant via two standard ECG pads (WelchAllyn, Buckinghamshire, UK) at the base of the sternum and the 6th intercostal space in tandem with a CHRM (Polar RS400, Polar Electro UK Ltd., Warwick, Great Britain) (see Figure 6.1). A signal test was conducted using the Actiheart software (Actiheart 4, CamNtech, Cambridge, UK), to examine if the R wave of each participant was being recorded adequately and to avoid any inaccurate reading during measurement due to high noise level or low signal. The signal test was set up with the individual data of each participant (stature, BM, predicted HR_{max} and HR_{sleep}) and updated at each visit. Participants were requested to walk around the laboratory for a period of five minutes during the signal test recording, as per the manufacturer's instructions. Prior to the commencement of each protocol, BLac concentrations were measured by taking approximately 5µl of whole blood from the fingertip for analysis via a portable unit (Lactate Pro Meter, Arkray B.V. Amstelveen, Holland). The Lactate Pro was employed due to its practical ease of use and given its reliability has previously been confirmed (Baldari et al., 2009). Oxygen uptake was measured continuously via an indirect calorimetry online gas analysis system (CPX Ultima Series; Medgraphics, Saint Paul, MN, USA), which was calibrated prior to testing with a 3L syringe for volume (Hans Rudolph; Shawnee, Kansas, USA), known concentrations of O_2/CO_2 and a zero calibration span gas. Participants wore a face mask (Hans Rudolph; Shawnee, Kansas, USA), secured tightly in order to minimise atmospheric exchange and were then positioned in the centre of 4 (1 x 1 metre) official competition mats. The pad holder was positioned directly in front of the participant for kicks to be conducted upon the command of each audio signal (see Figure 6.2).

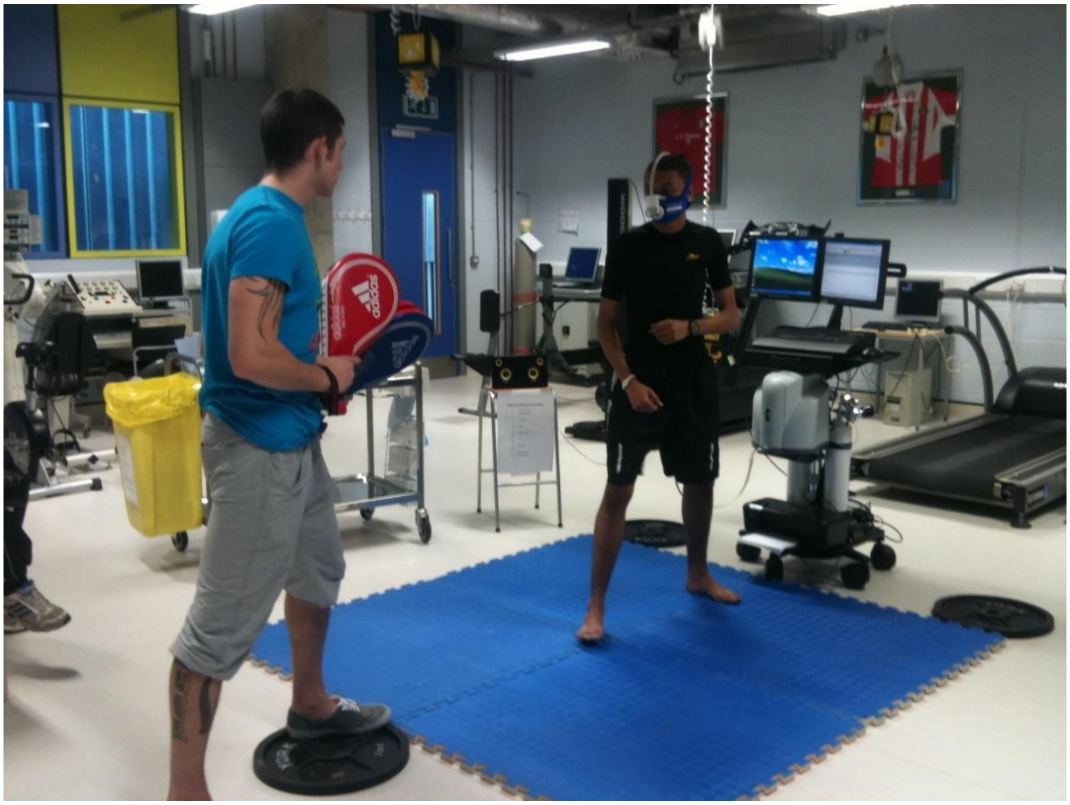


Figure 6.2. *STCP-W protocol set-up including position of participant, pad holder, indirect calorimetry online gas analyser, audio signal and blood collection facility.*

Measures of HR and BLac were recorded at the cessation of rounds 1, 2 and 3 in the same manner as baseline and RPE was also assessed via the Borg (1970) 6-20 scale. Data collection was recorded breath by breath on the indirect calorimetry system, every inter beat HR interval by the Actiheart and at the cessation of the protocol all data was immediately downloaded. Indirect calorimetry $\dot{V}O_2$, $\dot{V}CO_2$ ($L.min^{-1}$) and RER data were then organised into rounds 1, 2, 3 and rest periods 1 and 2 for each participant/protocol and converted into kcal using the table of Zuntz and Schumburg (1901) as updated by Lusk (1924).

6.2.3. Statistical Analyses

Descriptive statistics are provided for all variables (mean ± SD) and data were explored for normality using box plots. Statistical analysis was conducted using a two way within subjects ANOVA, based on the repeated measures design and interval data collection measurement, where sphericity was assumed using the Mauchly test. Bonferonni post hoc analysis was used to examine pairwise comparisons. Least squares regression analysis was used to assess the strength of association and validity of both HR and AEE measurements where CHRM recordings and indirect calorimetry were regressed against the Actiheart for each STCP-W protocol condition (Hopkins et al., 2009). Fixed bias was assessed by determining whether the intercept for the regression was different from zero and proportional bias was deemed present if the slope of the regression line was different from one. Random error was quantified using SEE from the regression. Predictive accuracy for each individuals HR and AEE measurement via the Actiheart was calculated and evaluated based on the mean of 95% PI. Cohen's *d* ES were calculated to highlight the AEE differences between time points during each STCP-W protocol condition, utilising the following quantitative criteria to explain the practical significance of the findings: *trivial <0.2, small 0.21-0.6, moderate 0.61-1.2, large 1.21-1.99* and *very large >2.0* (Hopkins et al., 2009). Statistical significance was established at an alpha level of $p < 0.05$ and all statistical analyses were carried out using SPSS for Windows version 24 (PASW, Chicago, Illinois, USA).

6.3. Results

6.3.1. STCP-W Protocol Physiological Responses

There was a main effect of time from baseline and across the three rounds for participants HR (p < 0.001), BLac (p < 0.001) and RPE (p < 0.001) measures in all STCP-W protocols. There were also main effects between all STCP-W protocols for HR (p = 0.001), BLac (p < 0.001) and RPE (p < 0.001), concomitant with significant interaction effects for BLac (p < 0.001) and RPE (p = 0.03), respectively. However, there was no interaction effect for HR due to similarities in round 1 responses between STCP-W 1:5 and 1:7 protocols (p = 0.07). Figure 6.3. highlights the perceptual and physiological responses for HR, BLac and RPE across all STCP-W protocols inclusive of pairwise comparisons.

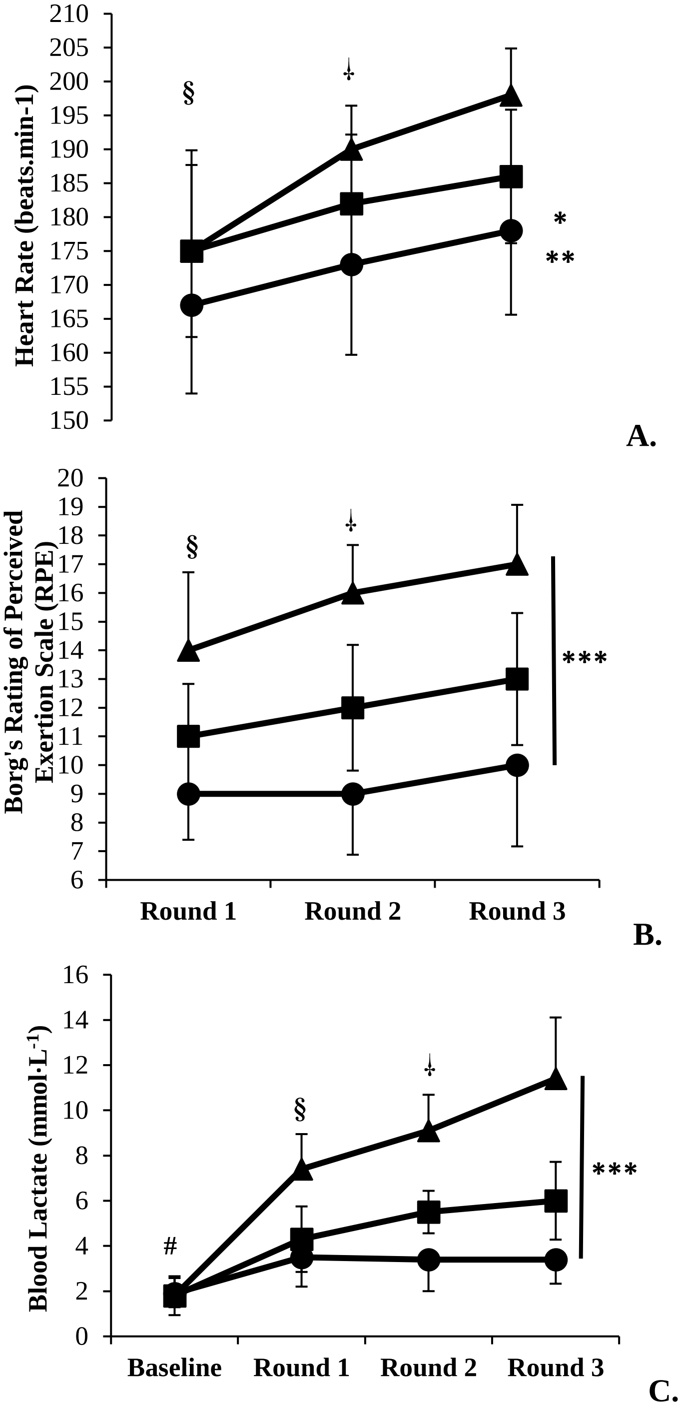


Figure 6.3. *(A.) HR, (B.) RPE and (C.) Blac perceptual and physiological responses to 1:7 (●), 1:5, (■) and 1:2 (▲) STCP-W protocols.*

= significant difference to Round 1, 2 and 3 ($p < 0.05$) **§** = significant difference to Round 2 and 3 ($p < 0.05$) ⸸ = significant difference to Round 3 ($p < 0.05$)
***** = significant difference to STCP-W 1:5 ($p < 0.05$) ****** = significant difference to STCP-W 1:2 ($p < 0.05$)
******* = significant difference between all STCP-W protocols ($p < 0.05$)

6.3.2. STCP-W Activity Energy Expenditure and Heart Rate Correlation and Regression Analyses

The slopes, intercepts, SEE and Pearson (*r*) correlations together with 95% PI for comparison of both HR and AEE are presented in Table 6.1. The random error associated with each HR measurement were relatively similar between STCP-W protocol 1:7 (1.11) and STCP-W protocol 1:5 (1.63), with an increased difference for STCP-W protocol 1:2 (4.03). The random error for AEE measurement in STCP-W protocol 1:7 was marginally lower (7.05) than both STCP-W protocols 1:5 (11.16) and 1:2 (13.26). The 95% PI for each HR measurement were again similar in magnitude between STCP-W protocol 1:7 (3.04) and STCP-W protocol 1:5 (4.45), with a larger difference for STCP-W protocol 1:2 (10.99). Similarly to random error the 95% PI for each AEE measurement was lower in STCP-W protocol 1:7 (19.25) compared to both STCP-W protocols 1:5 (30.50) and 1:2 (36.19), respectively. Both HR and AEE measurements were positively correlated with the criterion methods presenting a diverse range of correlations (*r*) and overlapping 95% CIs ($p < 0.05$).

The presence of both fixed and proportional bias was assessed by visual inspection of the regression lines for HR in Figure 6.4 A-C. and AEE in Figure 6.4 D-F. HR measurement across all STCP-W protocols showed a limited presence of proportional bias, with the slope of the respective lines being close to one. This was also the case for AEE measurements in STCP-W protocols 1:7 and 1:5, yet there was an increase in proportional bias demonstrated in STCP-W protocol 1:2. There was a minimal presence of fixed bias in HR measurement for both STCP-W protocols 1:7 and 1:5, with an increase in STCP-W protocol 1:2. For AEE measurement, there were divergent values demonstrating the presence of marginal fixed bias based on underestimation in STCP-W protocol 1:7, overestimation in STCP-W protocol 1:2 and improved agreement in STCP-W protocol 1:5.

Table 6.1. *Least Squares regression analysis (r) of the slopes, intercepts, SEE and the mean of 95% PI of Polar RS400 CHRM (HR) and indirect calorimetry (AEE) vs. Actiheart measurements across the varying STCP-W protocols.*

HR (bpm)		**MEAN ± SD**	**SLOPE**	**INTERCEPT**	**SEE**	***r***	**MEAN 95% PI #**
STCP-W 1:7	***Polar***	*172 ± 12.8*	*1.01 (0.93-1.09)*	*-1.10 (-15.16-12.96)*	*1.11*	**1.00 (0.98-1.00)*	*3.04 (6.08)*
	Actiheart	*172 ± 12.8*					
STCP-W 1:5	***Polar***	*181 ± 10.6*	*1.01 (0.86-1.14)*	*-0.10 (-25.53-25.32)*	*1.63*	**0.99 (0.94-1.00)*	*4.45 (8.89)*
	Actiheart	*181 ± 10.7*					
STCP-W 1:2	***Polar***	*188 ± 6.9*	*0.95 (0.34-1.57)*	*9.30 (-106.27-124.86)*	*4.03*	**0.84 (0.33-0.97)*	*10.99 (21.97)*
	Actiheart	*187 ± 6.1*					
AEE (kcal)							
STCP-W 1:7	***Indirect Calorimetry***	*85.1 ± 22.2*	*0.97 (0.67-1.26)*	*-9.70 (-39.41-20.02)*	*7.05*	**0.96 (0.77-0.99)*	*19.26 (38.51)*
	Actiheart	*98.1 ± 22.0*					
STCP-W 1:5	***Indirect Calorimetry***	*99.0 ± 24.7*	*0.93 (0.49-1.31)*	*7.16 (-38.54-50.16)*	*11.16*	**0.91 (0.57-0.98)*	*30.5 (61.00)*
	Actiheart	*101.8 ± 25.1*					
STCP-W 1:2	***Indirect Calorimetry***	*112.7 ± 21.5*	*0.74 (0.23-1.26)*	*38.33 (-14.37-91.03)*	*13.26*	**0.82 (0.28-0.97)*	*36.19 (72.37)*
	Actiheart	*100.0 ± 23.8*					

✱significantly correlated with criterion method. # PI ranges may be calculated by multiplying the 95 % PI interval by 2 (Ranges are in parentheses).

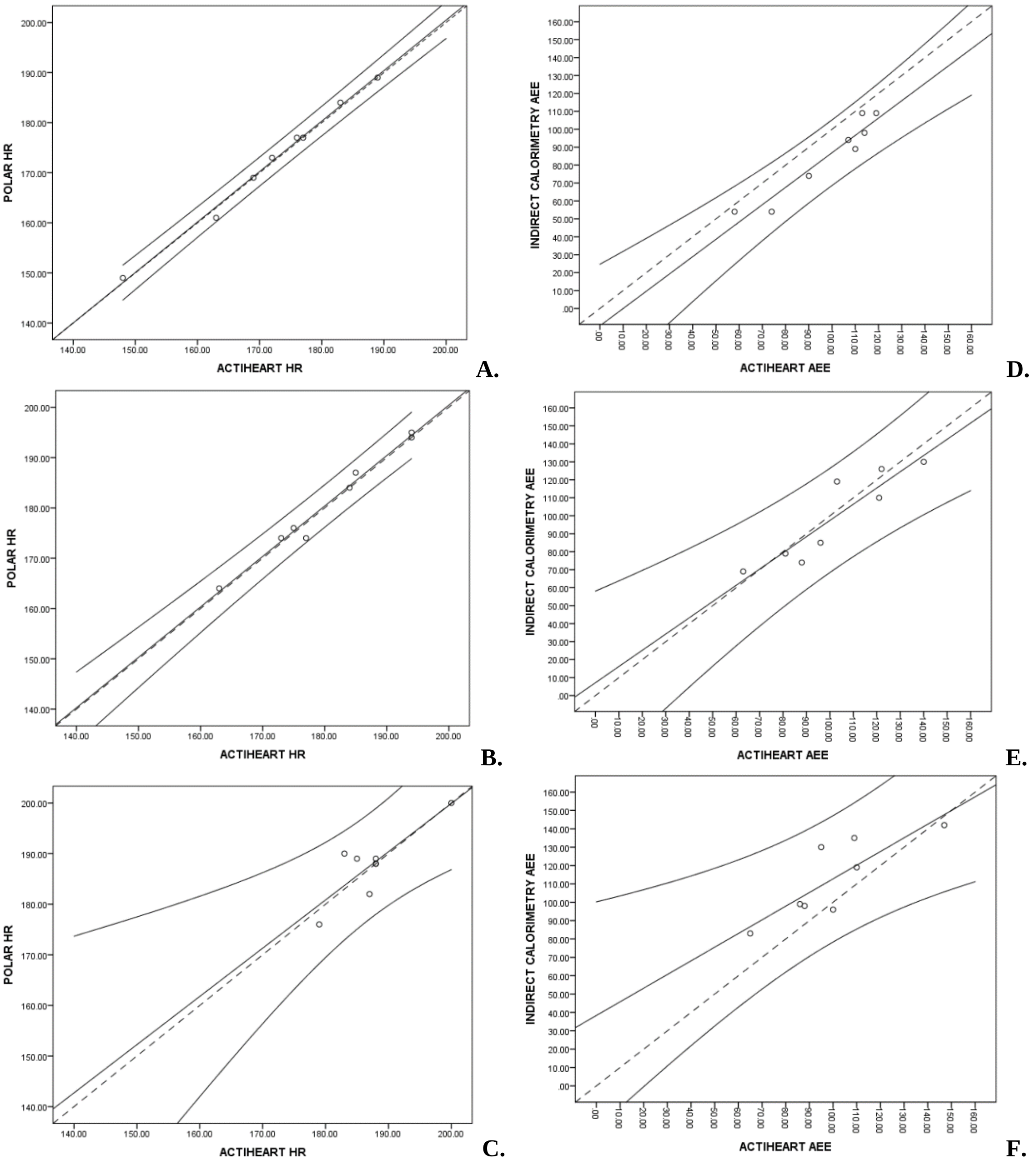


Figure 6.4. *Least squares regression plots of Polar RS400 CHRM (A-C) and indirect calorimetry (D-F) vs. Actiheart HR and AEE measurements during STCP-W 1:7 (A & D), STCP-W 1:5 (B & E) and STCP-W 1:2 (C & F) protocols.*

Plots indicate line of Unity (broken line), line of regression and 95% Prediction Intervals (outer solid lines).

6.3.3. Activity Energy Expenditure Effect Size Comparisons

Table 6.2 and Figure 6.5 A-C. presents ES and 95% CI's to examine the difference of mean values for specific time points across all rounds and rest periods also including total AEE measurement, where across all STCP-W protocols there were only trivial to moderate differences between the Actiheart and indirect calorimetry methods.

Table 6.2. *Effect size comparisons of mean values for time points across rounds and rest periods inclusive of 95% CI values for indirect calorimetry and Actiheart during STCP-W protocols 1:7, STCP-W 1:5 and STCP-W 1:2*

Timepoint	STCP-W 1:7	95% CI	STCP-W 1:5	95% CI	STCP-W 1:2	95% CI
Round 1	1.00	*(-0.11-2.14)*	0.64	*(-0.44-1.72)*	0.06	*(-1.11-0.99)*
Rest 1	0.04	*(-1.10-1.00)*	0.57	*(-1.64-0.50)*	0.86	*(-0.26-1.93)*
Round 2	0.58	*(-0.49-1.66)*	0.02	*(-1.06-1.03)*	0.53	*(-0.52-1.61)*
Rest 2	0.09	*(-1.15-0.95)*	0.13	*(-1.18-0.92)*	1.04	*(-0.07-2.18)*
Round 3	0.68	*(-0.42-1.74)*	0.07	*(-0.96-1.16)*	0.57	*(-0.50-1.64)*
TOTAL AEE	0.59	*(-0.49-1.66)*	0.12	*(0.94-1.16)*	0.57	*(-0.51-1.63)*

(Colours are indicative of outcome:
Blue = trivial <0.2; Green = small 0.21-0.6; Yellow = moderate 0.61-1.2)

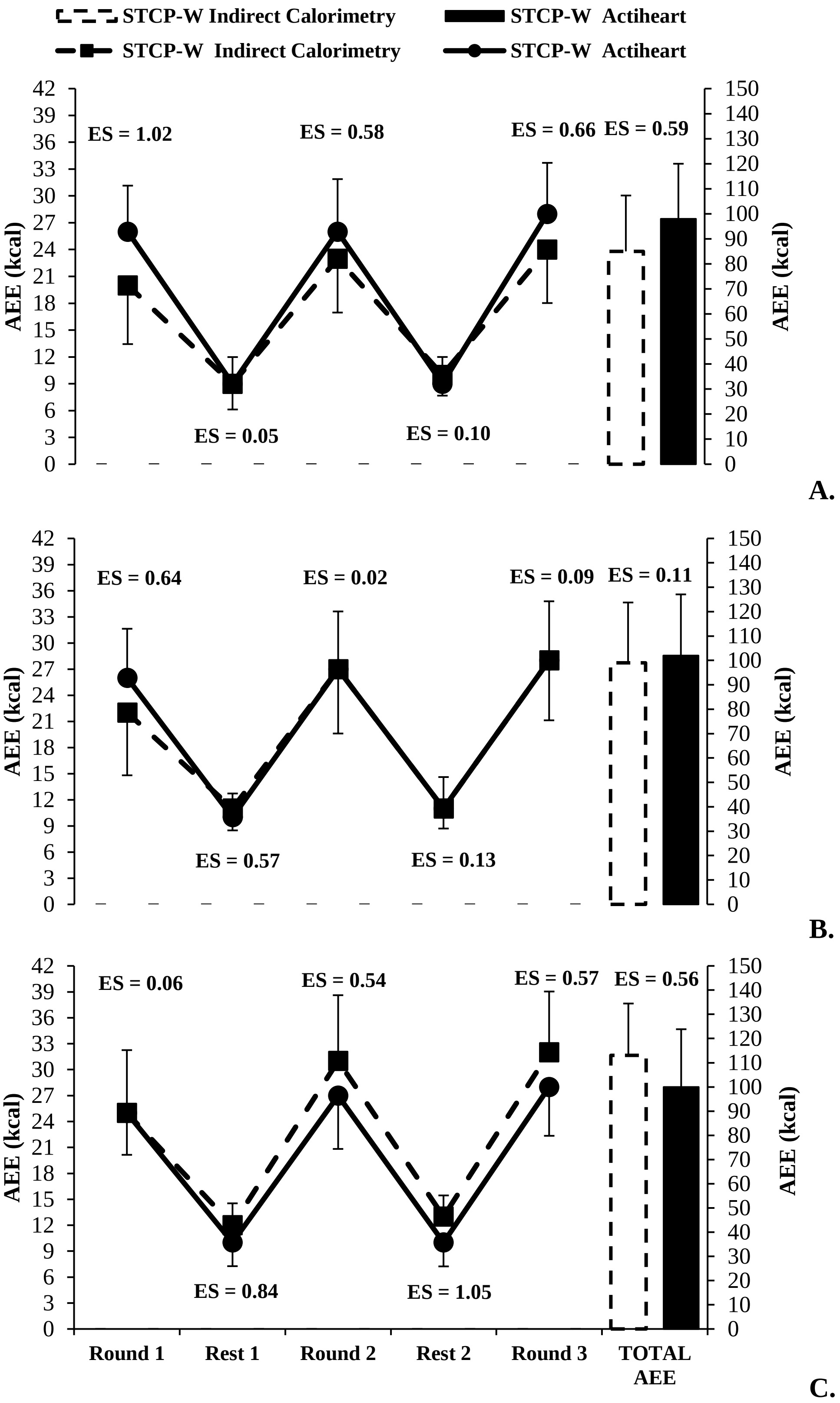


Figure 6.5. *Effect size comparisons of mean values for time points across rounds and rest periods including total AEE measured via indirect calorimetry and Actiheart during STCP-W protocols 1:7 (A.), 1:5 (B.) and 1:2 (C.).*

6.4. Discussion

The main aim of this study was to estimate AEE utilising laboratory and field based measures during an ecologically valid simulated Taekwondo competition protocol. This is the first investigation to examine the perceptual, physiological and AEE demands of pad based simulated Taekwondo bouts with varying activity:recovery ratios. Figure 6.3 highlights the differences in these responses across the protocols, which demonstrates the variance in respective perceptual and physiological demands and therefore effectiveness as measures of intensity. Based on this respective data, the ecological validity of protocols STCP-W 1:5 (competition intensity) and STCP-W 1:2 (hard intensity), was assessed by comparing the HR, BLac and RPE responses to those studies which have utilised the same measures in competitive, opponent and pad based simulation bouts (see section 2.4.3 and Table 2.6).

The mean round by round and total RPE responses for STCP-W protocol 1:5 were similar to those of competitive, opponent and pad based simulation bouts, whereas STCP-W protocol 1:2 values were up to 3-4 units higher at each time point. Conversely to Bridge et al. (2013), mean round by round and total HR values for the STCP-W protocol 1:5, were strikingly similar to those of the competitive and opponent based simulation bouts. STCP-W protocol 1:2 was also similar, despite being different to STCP-W protocol 1:5 values in the last two rounds and with values that are up to 8 beats·min^{-1} higher in round three, when compared to competitive and opponent based simulation bouts. These results may not be surprising, given that the intensity of STCP-W protocol 1:5 is set as the same activity:recovery ratio as in competition, whereas the intensity of STCP-W protocol 1:2 was considerably higher, due to the reduced recovery periods between kicking activities. The mean round by round and total BLac values for STCP-W protocol 1:5, demonstrated agreement to the other studies conducted in opponent simulated bouts with values that were 3-6 mmol.L^{-1} lower than those exhibited in competitive bouts. However, interestingly STCP-W protocol 1:2 presented values that were in direct contrast to the metabolic responses of competitive bouts across all time points. Lower intensities based on greater time for recovery between kicking activity in STCP-W protocol 1:5, may allow for reduced cardiometabolic responses and perception of effort, which has been highlighted in other combat sport based training activities with altered activity:recovery ratios (Baudry & Roux, 2009; Franchini et al., 2013). Data from these studies have also indicated the effectiveness of manipulating the physiological responses of specific combat sport activities to those similar of competitive bouts by reducing the within and between recovery component of activity profiles. A study by Smilios et al. (2018) demonstrated how the adaptation of recovery in this paradigm may come from the combined increases in cardiorespiratory demands. Additionally, Dulac et al. (1986) highlighted how repeated bouts of anaerobic efforts considerably increases plasma concentrations of both adrenaline and noradrenaline, which may induce catecholamine and cortisol interactions on the adrenal medulla stress response, thus elevating BLac levels. Regardless of these hypotheses, this study is in agreement with previous literature in demonstrating that the competition activity profile matched STCP-W protocol 1:5 showed low ecological validity, whereas the STCP-W protocol 1:2 shows high ecological validity, despite increased perceptual and cardiovascular demands in the latter rounds.

Examining a number of studies and focusing independently on the aerobic component of AEE, an investigation conducted by Yang et al. (2018) who assessed the effects of A/RWL on opponent based simulated bouts, highlighted an activity:recovery ratio of 1:7 with kicking based activity intervals of 1 second. In the control condition, mean AEE contributions per round were exhibited as 17-18 kcal, which is similar to the AEE measurement demonstrated in STCP-W protocol 1:7. Examining a number of other studies utilising opponent based simulated bouts (Campos et al., 2012; Lopes-Silva et al., 2018; Lopes-Silva et al., 2015) where the activity:recovery ratio is decreased to 1:5/6 with longer kicking activity intervals (1.5-2 seconds), mean AEE contributions are more similar to those demonstrated in protocols STCP-W 1:5 and 1:2 with averages of 23-26 kcal in round one, 28-30 kcal in round two and 29-32 kcal in round three. These comparisons show that the protocol was effective at creating indirect calorimetry aerobic AEE contributions, which reflected intensity based on the differing activity:recovery ratios. Whilst all of these aforementioned studies provide useful data on the AEE demands during specific Taekwondo based activities, they are not available for use without specialist expertise or equipment (see section 2.4.3). Therefore, alternative and more practical tools for the measurement of AEE is required for use in the field.

AEE is a key component of EA calculation, which is often incorrectly estimated and/or calculated and difficult to measure both validly and accurately in athletic populations, given the variability in assessment methods (Burke et al., 2018b). The importance of examining the potential for LEA status in international standard Taekwondo athletes cannot be understated, given the BM loss practices which are culturally inherent within the sport. The use of portable actigraphy with integrated accelerometry is becoming more popular when examining AEE in a host of activities (Shephard & Aoyagi, 2012) and a limited number of studies have utilised this technology with a Taekwondo athletic population (Cho, 2014; Cho et al., 2013). However, the portable actigraph utilised in these studies was a hip worn accelerometer, which does not take into account whole body movements, nor has this device been validated against either DLW or indirect calorimetry for AEE measurement during a range of free living and exercise based modalities (Brazeau et al., 2014; Correa et al., 2016; Dannecker et al., 2013; Johnson et al., 2015). The Actiheart unit utilised in this study, has previously been validated against both DLW (Rousset et al., 2015; Silva et al., 2015; Villars et al., 2012) and indirect calorimetry (Barreira et al., 2009; Brage et al., 2005; Crouter et al., 2008) for measurements of TEE and AEE in both free living and various physical activities. This is only the third study to utilise the Actiheart with an athletic population and also the third to do so with a laboratory based simulation protocol (Thompson et al., 2006; Wilson et al., 2013).

When assessed via least squares regression the Actiheart highlighted good agreement with the Polar RS400 CHRM for measures of HR across all conditions. For measures of AEE versus indirect calorimetry in STCP-W protocol 1:7, the Actiheart demonstrated marginal overestimation via the presence of fixed, yet minimal proportional biases. STCP-W protocol 1:2 also highlighted marginal underestimation of AEE, with divergent proportional biases, whereas STCP-W protocol 1:5 showed good agreement with both minimal fixed and proportional biases. The under and overestimation of AEE measurement with the Actiheart versus indirect calorimetry has been demonstrated in other studies (Calabro et al., 2014; Nichols et al., 2010; Wilson et al., 2013) across a range of diverse exercise modalities. Brage et al. (2006) highlighted how the error in AEE measurement may come from the movement of the Actiheart unit during exercise, given a 10 degree tilt from the horizontal position can result in a 3% reading error. Due to the increased activity and therefore movement in STCP-W protocol 1:2, this may explain some of the diverging values, however, this does not explain the over estimative values in STCP-W protocol 1:7. To combat this issue, the Actiheart manufacturer CamNtech have created a chest belt to hold the unit in position similar to a Polar WearLink®+, however, this was not commercially available for use during this study. Despite the differences in indirect calorimetry AEE measurement during protocols STCP-W 1:7 and 1:2, Table 6.2 and Figure 6.5 demonstrate that when individual time points across all rounds and rest periods are considered, these could be regarded as ecologically minimal based on trivial to moderate effect sizes. These findings are crucial in affording the possibility to examine AEE in Taekwondo training and competition based activities within ecologically valid settings. A greater understanding of the energetic cost of these activities, will aid in exploring the TEE of this demographic and prescribe periodised and adequate dietary strategies, allowing gradual BM losses whilst limiting the consequences of LEA which may lead to RED-S syndromes.

6.5. Conclusion

The data from this study demonstrates that by manipulating the activity profiles of pad based Taekwondo simulation protocols, the metabolic responses of competitive bouts can be matched, however, this results in higher cardiorespiratory and perceptual HR and RPE values in tandem with the increases in intensity. Despite divergent agreement between the AEE measurements displayed by the Actiheart and indirect calorimetry to each of the STCP-W protocols, given that these differences were ecologically minimal, this could justify its use in practice. This in turn can aid field based practitioners in providing a means to quantify the TEE of international Taekwondo athletes, therefore guiding dietary prescription and reducing the potential for LEA and RED-S during BM loss, which is habitually practiced in this athlete population.

CHAPTER 7.

Making Weight Safely: Manipulation of Energy Availability and Within Daily Energy Balance Without Symptoms of RED-S in an International Standard Taekwondo Athlete

7.1. Introduction

Previous studies (see section 2.6.6) and the results of Chapters 3 and 4, have highlighted that international standard Taekwondo athletes engage in making weight practices to both gain/reduce opponent advantages in competition, utilising a variety of methods which are deleterious to both health and performance. Furthermore, Chapters 3 and 4 have highlighted these athletes have poor nutritional knowledge, particularly when it comes to BM reduction and in the post competition phase undergo periods of rebound hyperphagia, potentially leading to BM and FM overshoot. Chapter 5 also elucidated that these athletes need to engage in a greater amount of A/RWL than previously characterised, particularly when making weight for the respective OG weight categories.

Parallel to the practices and behaviours described above, reductions in EI with concurrent increases in AEE, may result in LEA, leading to the potential for RED-S consequences (see section 2.8.5.) Kasper et al. (2018) is the only investigation to characterise the consequences of a prolonged energetic deficit in combination with A/RWL practices within a combat sport athlete case study. The data from this enquiry demonstrated a number of RED-S related health and performance outcomes, but was unable to provide details of EA status, based on the absence of AEE measurement due to the athlete's grappling based training activities. Given the results of Chapters 5 and 6, there is now a possibility to measure both body composition and AEE within Taekwondo activities, with a greater degree of accuracy and reliability compared to criterion methods, which are not tenable to be used in the field. This can now allow an examination of EA status in combat sports athletes, in tandem with measurements of potential RED-S syndromes.

Therefore, the aim of this study was to introduce a structured nutritional and training intervention for a male international level Taekwondo athlete, aiming to make weight for a specified weight category. Secondary to this, utilising the methods described in section 2.8.4 and Chapters 5 and 6, a subsequent aim was to highlight the potential for LEA and the effects of the intervention on WDEB. Finally, the study also aimed to investigate the potential for RED-S consequences during the intervention, concomitant with an examination of rebound hyperphagia in the post competitive period.

7.2. Methods

7.2.1. Athlete Overview

The Athlete was a Caucasian male (age: 19 years; stature: 166.3cm; BM: 72.5 kg) with over 5 years' competitive experience at international level. The Athlete typically competed 10 times per year in the -68 kg Feather weight category, habitually requiring losses of 4-5 kg. The Athlete decided to further reduce his BM, to compete in the -63 kg Bantam weight category at the 2018 British University Championships, where a semi-final placing would secure national team selection for the 2018 European University Games.

The following excerpts were articulated by the Athlete at baseline (methods described in section 7.2.4), highlighting their views on previous making weight practices:

An overview of methods to lose BM: '*I start losing about 2-3 weeks beforehand, I start cutting the carbs, just try and progress it from there and then dehydrate…I reduce the carbs because they are what keeps the fat on...To dehydrate I use more layers in training, so, more clothing, using stuff like sweatsuits, restricting water intake during training, just trying to increase the sweating, you know, more out rather than in.'*

On the psychological and physiological symptoms of BM loss: '*Drained mentally and physically. Really tired, fatigued, quite slow, sluggish when I'm training…Mentally just not motivated, not enthusiastic…I'd get mood swings quite often when I do the diets. I start snapping at people and getting quite upset, just over nothing, breaking down crying for no reason…Fucking tough and quite a lonely and demoralising process, if that makes sense. It was difficult balancing your training, social life alongside it as well.'*

The Athlete required a loss of >9.5 kg (>13% BM) in a period of eight weeks to meet the weight category limit. In order to assess the potential for both the health and performance consequences of RED-S, a multi methodological approach was employed throughout the intervention period. Measurements were taken daily and also at set intervals inclusive of baseline (-8 WK), four weeks (-4 WK), seven weeks (-1 WK), the day prior to weigh in (PRE CUT), weigh in day (WI), 24 hours post competition (+1 D), and one week post competition (+1 WK), as detailed in the following sections and highlighted in Figure 7.1. The Athlete gave written informed consent to undertake the intervention and the case study was approved by the Liverpool John Moores University research ethics committee.

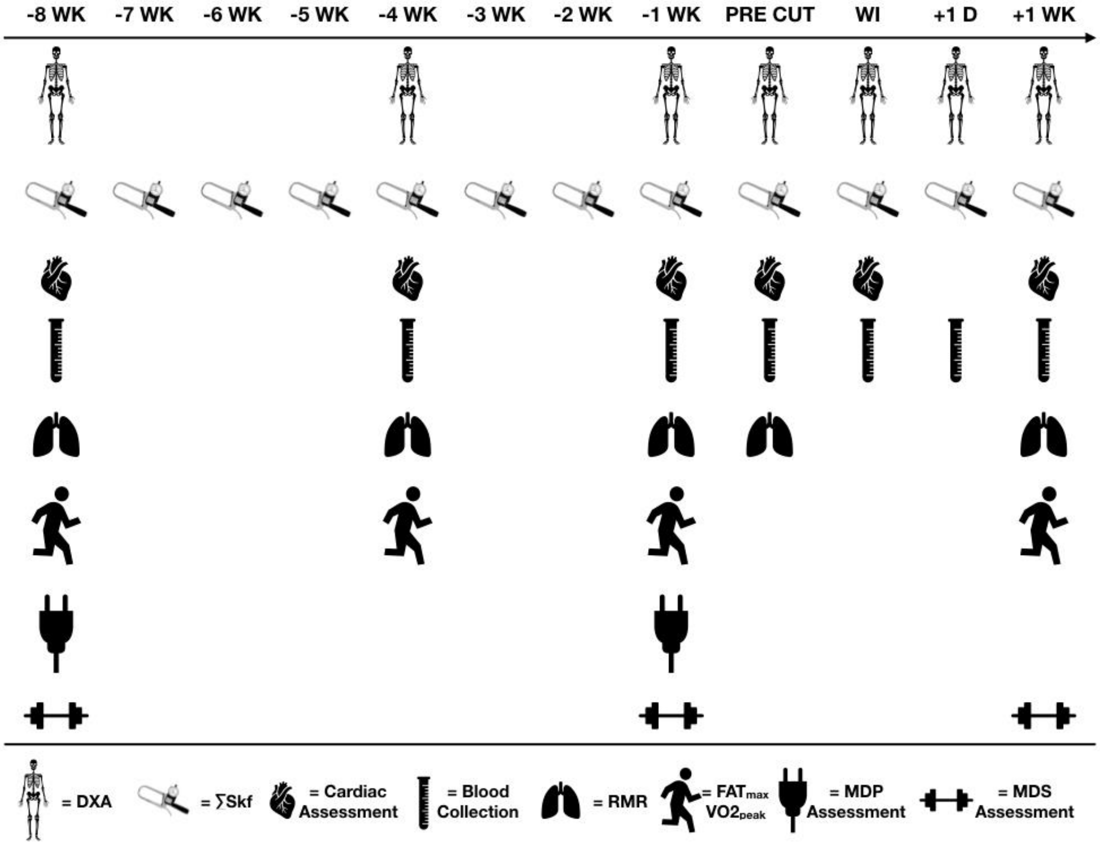


Figure 7.1. *Overview of measurements taken during the intervention period.*

7.2.2. Anthropometric and Physiological Assessment

Stature and BM: Stature was measured to the nearest 0.1 cm using a free standing stadiometer and BM was determined to the nearest 0.01 kg on digital scales (Seca 702; Seca GmbH, Hamburg, Germany). Body composition was assessed via DXA (QDR Series Discovery A; Hologic Inc., Bedford, MA, USA - software version 12:4:3) to generate LM, FM and FM% values, in tandem with anthropometric $\sum_{8SKf}$ (Harpenden, Baty Int., West Sussex, Great Britain) according to the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart & Marfell-Jones, 2011). All subsequent scans, analyses and anthropometric measures were conducted by an Ionising Radiation Medical Exposure Regulations (IR(ME)R) and ISAK registered anthropometrist (see section 5.2.2).

Resting Metabolic Rate and $\mathbf{RMR_{ratio}}$: RMR was examined utilising an indirect calorimetry open hood system (GEM Open Circuit Indirect Calorimeter; GEMNutrition Ltd., Warrington, UK), which was calibrated prior to testing via known concentrations of O_2/CO_2 and a zero calibration span gas. This calibration was then validated by conducting an ethanol burn, to confirm an established RER value of 0.67. The Athlete was directed to lay in a supine position on a medical bed, with a ventilated hood placed across their head and shoulders (wrapped with plastic sheeting to minimise any external atmospheric exchange), then instructed to relax, lay as still as possible and breathe normally. The test was conducted over a 30 minute period within a quiet laboratory environment, with only the last 20 minutes being included in the subsequent data analysis (Compher et al., 2006). The averaged breath by breath $\dot{V}O_2$ ($L.min^{-1}$) for the collection period was multiplied by 60 (representing minutes) and then 24 (representing hours) to the averaged RER/kcal value (see section 6.2.2).

The RMR_{ratio} was calculated by dividing the values between both RMR_{meas} and RMR_{pred} indices, where RMR_{pred} was established via the Cunningham equation ($RMR = LM \times 21.6 + 501.6$) (Cunningham, 1980). An RMR_{ratio} of <0.90 was classified to define instances of suppressed RMR, indicating potential energy deficiency (Staal et al., 2018; Torstveit et al., 2018), with RMR_{meas} values below those of RMR_{pred} also used to calculate instances of AT by subtraction of total amounts (Muller et al., 2015).

Venous Blood Analyses: The Athlete had blood samples drawn from the antecubital vein of the left arm by a trained phlebotomist, which were collected into singular ethylenediaminetetraacetic acid (EDTA), lithium heparin (LHep) and serum separator tube (SST) 5 ml vacutainers (BD Vacutainer; Becton, Dickinson and Company, Franklin

Lakes, New Jersey, USA). EDTA and LHep samples were placed on ice and the SST samples were kept at laboratory temperature. Blood plasma (EDTA/LHep) and serum (SST) samples were centrifuged for 10 minutes at 4°C and a relative centrifugal force of 1200*g* as per laboratory standard operating procedures. 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 (see Figure 7.2.). All biochemical measurements of endocrine, renal, liver, electrolyte, lipid and bone turnover biomarkers were conducted by Royal Liverpool University Hospital.

Figure 7.2. *Venous blood collection and centrifuging/aliquoting of samples.*

Insulin (I), β-carboxy-terminal cross-linked telopeptide (β-Ctx), total procollagen type 1 N-terminal propeptide (P1NP), parathyroid hormone (PTH), cortisol (C), luteinizing hormone (LH), follicle stimulating hormone (FSH), testosterone (T) and sex hormone binding globulin (SHBG) were assessed via immunoassay with chemiluminescence detection on a Roche Cobas e601/602 Modular analyser (Roche Diagnostics Ltd. Burgess Hill, Great Britain) and for Insulin like Growth Factor 1 (IGF-1) on an IDS iSYS Analyser (Immunodiagnostic Systems Holdings plc., Tyne & Wear, Great Britain). Urea (U), creatinine (Cr), albumin (ALB), total protein (TP), globulin (GLOB), bilirubin (BR), calcium (Ca^+), phosphate (Ph), total cholesterol (TC), high density lipoprotein cholesterol (HDL), low density lipoprotein cholesterol (LDL) 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. Individual inter/intra assay coefficient of variation (CV) and sensitivity (replicates of the zero standard) are all presented in Table 7.1. Sodium (Na^+), was examined via potentiometry ion selective electrode (ISE) on a Roche Cobas ISE analyser (Roche Diagnostics Ltd. Burgess Hill, Great Britain) with a respective CV of <1.5%.

Table 7.1. *Respective blood biomarker CV% range and sensitivity* of measurement*

Biomarker	CV%	CV Range	Sen*	Biomarker	CV%	CV Range	Sen*
I (pmol/L)	<4.9	41.2 – 2949.0	1.39	**Cr (µmol/L)**	<1.1	68.3 – 2286.0	5.0
IGF-1 (nmol/L)	<7.2	2.9 – 39.7	0.58	**TP (g/L)**	<2.5	50.7 – 89.3	2.0
T (nmol/L)	<4.4	0.3 – 45.8	0.09	**ALB (g/L)**	<1.5	28.9 – 59.1	2.0
C (nmol/L)	<3.8	3.1 – 1592.0	1.5	**GLOB (g/L)**	<2.1	17.5 – 41.2	2.0
LH (U/L)	<2.2	6.2 – 164.0	0.10	**BR (µmol/L)**	<3.3	9.1 – 544.0	2.5
FSH (U/L)	<3.7	6.0 – 178.0	0.10	**Ca^+ (mmol/L)**	<3.5	0.6 – 4.5	0.2
SHBG (nmol/L)	<4.0	14.9 – 219	0.35	**PH (mmol/L)**	<1.4	0.7 – 6.2	0.1
PTH	<6.5	2.8 – 27.2	0.13	**TC (mmol/L)**	<1.6	2.0 – 17.9	0.1
P1NP (µg/L)	<4.1	12.8 – 1140.0	5.0	**HDL (mmol/L)**	<1.5	1.2 – 2.7	0.1
β-Ctx (µg/L)	<5.7	0.06 – 4.64	0.01	**LDL (mmol/L)**	<2.1	1.5 – 6.1	0.1
Na^+ (mmol/L)	<1.5	87.6 – 153.0	10.0	**TG (mmol/L)**	<1.9	1.2-9.2	0.1
U (nmol/L)	<1.3	7.2 – 35.0	0.5				

Hydration Status: Urine (U_{osm}) and plasma (P_{osm}) osmolality were examined for subsequent hydration status. The Athlete was instructed to collect a sample of urine mid flow, into a 5 ml sterilised container (Fisher Scientific, Loughborough, Great Britain), which was immediately assessed via a hand held portable unit (Osmocheck, Vitech Scientific, West Sussex, Great Britain) for the measurement of U_{osm} refractive index measured in $mOsmols \cdot kgH_2O^{-1}$. The unit was calibrated by placing a small sample of distilled water on the unit clear daylight plate and pressing the zero calibration button (see Figure 7.3). This was then repeated for a sample of urine and pressing the start button. Assessments were made in triplicate with the mean of the values being recorded and zero calibration conducted between each test. P_{osm} was assessed via freezing point depression on an Advanced Micro-Osmometer 3320 (Advanced Instruments, Norwood Massachusetts, USA), which was calibrated utilising both 50 and 850 $\text{mOsmols} \cdot \text{kgH}_2\text{O}^{-1}$ calibration standard solutions (Advanced Instruments, Norwood, MA, USA). Both methods have been previously highlighted as having good agreement in regards to validity, accuracy and reliability of osmolality measurement for assessment of hydration status (Sparks & Close, 2013).

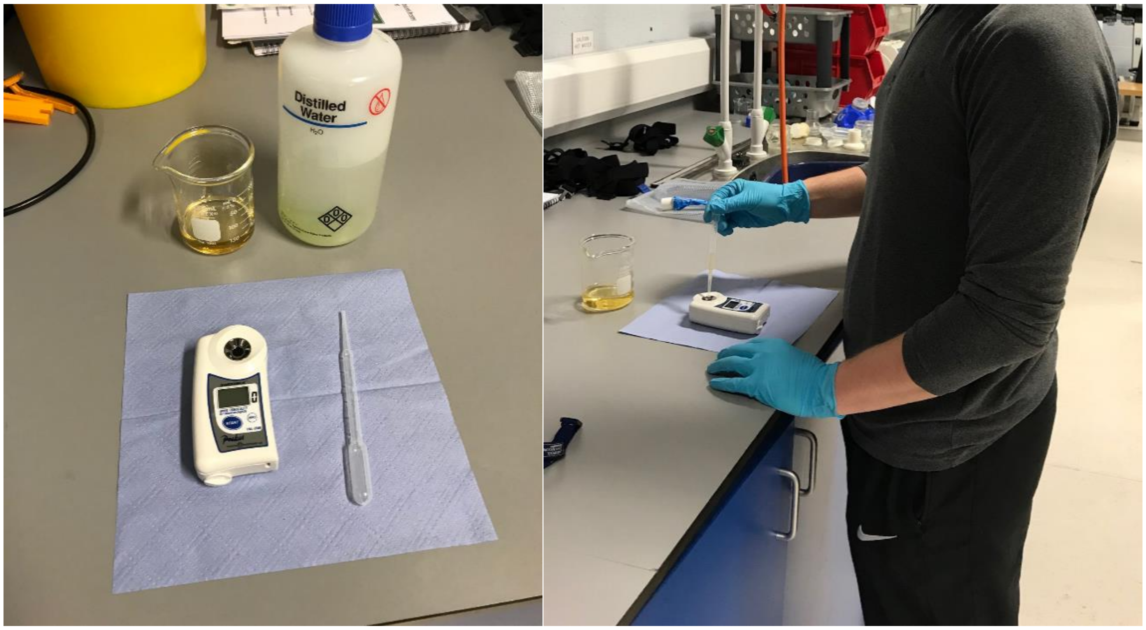


Figure 7.3. *U_{osm} equipment and assessment.*

Cardiac Assessment: Cardiac assessment was conducted on the Athlete prior to exercise testing via a 12-lead electrocardiogram (ECG) (in a supine position) and echocardiography (in an opposing prostrated position), which included standard 2D Doppler and tissue Doppler imaging inclusive of myocardial speckle tracking (see Figure 7.4) (Oxborough et al., 2014). Derived indices of HR, cardiac output (CO) and deformation from the left and right ventricles, were established via alterations in the structure of the left ventricular end-diastolic volume (LVEDV) and right ventricular diastolic area (RVDAREA), also inclusive of function via left ventricular ejection fraction (EF) and right ventricular fractional area change (RVFAC). All ECG/echocardiography scanning and subsequent analyses were conducted by a clinical cardiac physiologist registered with the British Society of Echocardiography.

Figure 7.4. *ECG and echocardiography assessment*

Cardiorespiratory and Substrate Utilisation Assessment: Combined maximal fat oxidation (FAT_{max}) and aerobic cardiorespiratory capacity ($\dot{V}O_{2peak}$) were assessed via an incremental exercise test protocol performed on a motorized treadmill (h/p/cosmos Pulsar; h/p/cosmos Sports & Medical gmbh, Nussdorf-Trainstein, Germany). Oxygen uptake was measured continuously via an indirect calorimetry online gas analysis system (CPX Ultima Series; Medgraphics, Saint Paul, MN, USA) (calibrated as in section 6.2.2). Prior to testing, the Athlete was connected to a safety harness and instructed to wear a facemask (Hans Rudolph; Shawnee, Kansas, USA), which was secured tightly in order to minimise external atmospheric exchange and then connected to the indirect calorimetry system. After a 2 minute normalisation period, the test began with 3 minute stages at treadmill speeds of 6, 7, 8, 9, 10 and 11 $km \cdot hr^{-1}$, followed by 2 minute stages at 12, 14 and 16 $km \cdot hr^{-1}$. On completion of the 16 $km \cdot hr^{-1}$ stage, the treadmill was inclined by 1% every 1 minute, until volitional exhaustion despite strong verbal encouragement. Throughout the test, the Athlete wore a HR monitor (Polar V800; Polar Electro UK Ltd., Warwick, Great Britain) (see section 6.2.2), with HR values being recorded throughout the test. Raw $\dot{V}O_2$, $\dot{V}CO_2$ ($L.min^{-1}$) and RER data were mean ± SD into individual time periods, converted into kcal (as per the calculation for RMR) and also FAT_{max} utilising the following equation: $g \cdot min^{-1} = (1.695 \times \dot{V}O_2) - (1.701 \times \dot{V}CO_2)$ (Jeukendrup & Wallis, 2005). All data inclusive of HR were then inputted into a Microsoft Excel (Microsoft UK, Reading, Great Britain) table to generate subsequent *FAT_{max}, Aerobic, Threshold, Anaerobic* and *Interval 1 & 2* training zones based on $\dot{V}O_{2peak}/HR_{max}$ and then plotted against attributable running speeds, which could be prescribed for cardiorespiratory based training sessions (see section 7.2.8).

All tests took place under standard laboratory conditions (room temperature 20.0 ± 1.5°C, humidity 38.5 ± 4.0% and barometric pressure 750.2 ± 6.5mmHg), were performed at the same time of day (9.00-11.00 am), after a 12 hour fast (with no fluid ingestion prior to the DXA and hydration assessments) and the Athlete was requested to refrain from exercise the day prior to assessment (Nana et al., 2012)

7.2.3. Muscular Strength and Power Assessment

Ballistic and Reactive Strength: Ballistic strength was assessed via both vertical SJ and CMJ. The SJ involved directing the Athlete to squat approximately 90° of knee flexion, maintaining the position for three seconds and followed by a full extension of the legs on the command *'jump'*. The CMJ was performed under the same conditions, but involved flexion followed by immediate full extension without command. Reactive strength was assessed via a vertical bounce drop jump (BDJ). The Athlete was directed to stand on top of a drop box at a set height of 40 cm, then instructed to fall off the box (without stepping down or jumping) and rapidly jump with legs in full extension, as quickly as possible once they made contact with the ground. All jumps were repeated three times, with standardised procedures including fixed akimbo hand positions. Jump height (JH) from both tests and ground contact time (GCT) during the BDJ were recorded using an optical acquisition system (Optojump Next, Microgate, Bolzano-Bozen, Italy – software version 1.12.1.0) and then utilised to calculate EUR (McGuigan et al., 2006) and reactive strength index (RSI) (Flanagan & Comyns, 2008). Coefficient of variations (CVs) were 1.9-4.0% for SJH, 1.5-4.0% for CMJH, 3.3-5.2% for BDJH and 8.5-10.6% for GCT, respectively.

Maximal Dynamic Strength: MDS was assessed via 1RM upper and lower bilateral bench press and squat exercises utilising an Olympic barbell and weight plates (Eleiko International, Halmstad, Sweden). Prior to testing, the Athlete cycled for five minutes on a stationary bicycle (Wattbike Pro; Wattbike UK, Nottingham, Great Britain) at 100 Watts (W). For the bench press exercise, the Athlete positioned themselves on a flat horizontal bench rack (Perform Better Ltd. Southam, Great Britain) with the barbell placed on a set of pins at a height conducive to their arm length and with the spotter standing behind. The Athlete then gripped the barbell in the same hand position for each attempt and was assisted into the starting position from the barbell rack upon the command of *‘three, two, one’*. Once the bar was in position for the exercise (in alignment with the anterior deltoids and sternum), the spotter stated *‘your bar’* and upon the Athlete stating *‘my bar’* the barbell was then released by the spotter. A successful attempt was only recorded when the Athlete touched their sternum in flexion during the descent and fully extended the arms in the ascent of the movement and upon failure the barbell was redelivered to the bench by the spotter (Moir, 2012). The squat exercise was performed within a power rack (Perform Better Ltd. Southam, Great Britain) and the Athlete reconfigured the barbell J hooks to a height in line with their anterior deltoid. The Athlete then positioned themselves in the centre of the barbell, with hands griped in parallel and so it was resting on the posterior trapezius in a high bar pinched position. The Athlete semi squatted to deliver the barbell from the J hooks and stood in the centre of the power rack, with foot position wider than the pelvis (in alignment with the shoulders and feet turned at 45°). A successful attempt was only recorded when the Athlete performed a squat movement at approximately 90° of knee flexion in the descent, followed by a full extension of the legs in the ascent and with the bar re-delivered to the J hooks. Upon failure the barbell was delivered to the power rack catches, set just below the Athlete 90° knee flexed position (Moir, 2012). For both exercises the Athlete performed a readiness set of ten repetitions with the barbell, then interspersed with 2 minute rest periods performed ten repetitions at 50%, five repetitions at 75% and one/two repetitions at 90% of calculated 1RM. All attempts were commenced after 3-5 minutes recovery and the load was exponentially increased until failure occurred (Haff & Triplett, 2016).

Maximal Dynamic Power: MDP was assessed via both upper and lower force velocity (F/V) profile assessment in the bench press and squat exercises, respectively. Utilising the same lifting procedures for both exercises, the Athlete performed three maximal attempts at 20, 40, 60, and 80% of tested 1RM load, interspersed by three minutes of recovery. Combined eccentric/concentric average Power (AP – W), Force in Newton's (AF – N) and Velocity in meters per second (AV – $m \cdot s^{-1}$) were recorded by a linear encoder (MuscleLab version 4010, Ergotest, Porsgrunn, Norway – software version 8.31) mounted perpendicular to the line of movement in each exercise. The distance in cm that the encoder displaced during each attempt was also recorded to assess consistency, allowing a maximum of 5 cm difference to be included in the subsequent data analysis. Data were expressed absolutely for the bench press and relatively to BM for the squat, with AF values on the Y axis and AP values on the Z axis plotted against AV values on the X axis to generate subsequent upper and lower F/V profiles and MDP curves.

The SJ, CMJ, BDJ and MDS tests were performed on the same day as the anthropometric and physiological assessments (17.00-19.00 pm), whereas the MDP test was performed at the same time on the following day. All the aforementioned tests were administered by a United Kingdom Strength and Conditioning Association accredited practitioner and took place under standard gymnasium conditions (room temperature 21.0 ± 1.5°C, humidity 40.5 ± 5.0% and barometric pressure 755.5 ± 3.5mmHg), after a minimum of three hours postprandial feeding period.

7.2.4. Psychological Assessment

Profile of Mood States: Psychological profile was assessed by both a POMS (McNair et al., 1971) and semi structured interviews. The POMS scale consist of 65 adjective words, which can be classified into 6 subscales. The Athlete was asked to decide how they had been feeling since their last POMS assessment and select an appropriate statement on a 5 point Likert scale (0-4), consisting of *Not at All, A Little, Moderately, Quite a Lot* or *Extremely* for each word. Each subscale was represented as *Tension* (9 words: 0-36 score), *Depression* (15 words: 0-60 score), *Anger* (12 words: 0-48), *Vigour* (8 words: 0-32 score), *Fatigue* (7 words: 0-28 score) and *Confusion* (7 words: 0-28 score). Individual scores were then plotted, to examine the profile of each subscale with an iceberg profile resulting in high vigour representing an optimal mood and an inverted iceberg profile demonstrating low vigour, indicative of a negative mood profile. The subscale score for *Vigour* was subtracted from combined aforementioned subscales to generate a total mood disturbance (TMD) score on a scale of -32-200 with lower to higher scores representative of optimal and negative mood profiles, respectively. The POMS was administered via an online platform (https://www.brianmac.co.uk/poms.htm#ref), with no time limit for responses and the Athlete was instructed to highlight if he was unsure about any of the words. All values were subsequently plotted to generate both POMS profile line graphs and TMD bar graphs, to examine differences between intervention time periods.

Semi Structured Interviews: Semi structured interviews and subsequent questions were conducted, generated and analysed in the same manner as described in Chapter 4 (see section 4.2.2 & 4.2.3). Additional questions were made on the basis of the specific time periods during the intervention i.e. prior to weigh in, pre-cut, post cut, weigh in day, post weigh in, competition day, post competition etc. and were generated to reflect the Athletes perceptions, thoughts, attitudes, emotions and behaviours throughout each phase. Psychological assessments were conducted at -8 WK, -4 WK, -1 WK, PRE CUT, WI, +1 D and +1 WK.

7.2.5. Daily Wellness/Training Load/Sleep Monitoring Assessment

Daily Well Being Score: Each morning upon waking during the intervention period and one week post, the Athlete was requested to report their BM and perception of wellness via WhatsApp cell phone application (WhatsApp; WhatsApp Inc. Mountain View, California, USA). BM was recorded in the same manner as in Chapter 5 (section 5.2.2). The Athletes perception of wellness was assessed via a Daily Well Being Score (DWBS) as proposed by McLean et al. (2010). The DWBS examines *Fatigue, Sleep Quality, General Muscle Soreness, Stress Level* and *Mood* on a 1-5 Likert scale, which is described by statements of perceived feeling. The sum of all five scores is utilised to characterise overall wellbeing with <7 indicative of low, 8-16 moderate and 17> high scores.

Internal/External Training Load: Training load was assessed by both internal and external monitoring tools (Halson, 2014). Internal training load was examined by the s-RPE method, as proposed by Foster et al. (1995), whereby the Athlete was requested to report their perceived exertion for all training throughout the intervention period on a category ratio scale of 1-10 (Borg et al., 1987), no later than 30 minutes post session via WhatsApp cell phone application (WhatsApp; WhatsApp Inc. Mountain View, California, USA). This was then multiplied by the training time in minutes to calculate internal training load as follows: *s-RPE Load = ratio RPE score x training duration (minutes)*. External training load in all training sessions was assessed via HR monitoring (Polar V800; Polar Electro UK Ltd., Warwick, Great Britain), where specific profiles were created for each type of training modality and specific HR zones (*Very Light, Light, Moderate, Hard, Very Hard*) designated based on $\dot{V}O_{2peak}/HR_{max}$ testing, as described in section 7.2.2 and updated after every testing session. The HR data was downloaded weekly and uploaded to the Polar Flow online application (https://flow.polar.com/) for subsequent storage and analysis.

Sleep Assessment: Sleep Monitoring was assessed via both a wrist worn portable actigraphy unit (Actiwatch 4, Cambridge Neurotechnology Ltd., Cambridge, Great Britain) in conjunction with the Consensus Sleep Diary (CSD) (Carney et al., 2012). The Actiwatch was worn on the non-dominant wrist and set to an epoch length of 1 minute. The Athlete pressed the marker button on the Actiwatch for 2-3s upon lights off (bedtime) and again at lights on (final awakening) the following morning. The Athlete was requested to complete the CSD within an hour of being awake, with questions relating to bedtime, sleep latency, wake up time and the number of awakenings. Both the Actiwatch markers and the CSD were used to determine bedtime, sleep onset, wake and get up times, so that sleep behaviour could be automatically calculated using the appropriate Actiwatch software (Actiwatch activity and sleep analysis version 5.24, Cambridge Neurotechnology Ltd, UK). The following sleep parameters from the Actiwatch analysis were used: sleep duration (hours:minutes), sleep latency (minutes), sleep efficiency (%), fragmentation index (restlessness) and total activity score (number of activity counts).

7.2.6. Energy/Fluid Intake and Non Exercise Activity Thermogenesis/Exercise Energy Expenditure Assessment

Throughout the intervention period all meals were provided for the Athlete via an external food preparation company (Fuel Station Ltd. Liverpool, Great Britain). Respective EI and macronutrient contents for all meals were derived from periodic DXA established LM data and Atwater factors (Atwater & Benedict, 1902) for CHO (1g = 4.0 kcal), PRO (1g = 4.0 kcal) and FAT (1g = 9.0 kcal) values. Fluid intake was monitored by the Athlete, where all drinks were ingested from a 1 litre (L) sports bottle with pre designated markings measured to 10 ml and was subsequently reported at the end of each day, throughout the entire intervention period. In the +1 WK phase, all EI was reported via the ‘*Snap-N-Send’* method (Costello et al., 2017), where images of all foods and drinks consumed during the entire period were recorded and sent via WhatsApp cell phone application (WhatsApp; WhatsApp Inc. Mountain View, California, USA). Each image was then subsequently analysed by a Sport and Exercise Nutrition Register performance nutritionist, where EI/macronutrient and fluid distribution were estimated via Nutritics dietary analysis software (Nutritics Ltd., Swords, Co. Dublin, Ireland). The Polar V800 HR watch (Polar Electro UK Ltd., Warwick, Great Britain) also acted as an activity monitor via an internal 3D accelerometer, which recorded wrist movements. This was utilised to examine NEAT via the Polar Flow application as calculated by the removal of RMR_{meas} and EEE. EEE in all training sessions was assessed via an Actiheart unit and calibrated/utilised as described in Chapter 6 (section 6.2.2).

7.2.7. Within Daily Energy Balance and Energy Availability Assessment

WDEB (Benardot, 2013) was employed to assess the total daily 24 hour fluctuations in EB (see section 2.8.4) and employed utilising the methodology of Torstveit et al. (2018) as follows:

EI - *Provided/estimated via methods described in section 7.2.6*

DIT - *Calculated as 10% of mixed meal composition in 6 hour postprandial period (Hour 1 - 3%; Hour 2 - 2.8%; Hour 3 - 1.9%; Hour 4 - 1.2%; Hour 5 - 0.7% and Hour 6 - 0.4% (Reed & Hill, 1996).*

EIT - *Calculated as 25% of alcohol intake in 5 hour postprandial period evenly dispersed as 5% per hour (Suter et al., 1994).*

EEE - *Estimated using the gross measure of AEE from the Actiheart unit (or taken from the average measure of accumulated TKD competition studies i.e. 100 kcal) then calculated into net EEE measure by removing REE for period of exercise non inclusive of NEAT (Net EEE = gross AEE - REE / 60 x exercise time) (Loucks, 2014).*

EPOC - *Estimated as 5% of net EEE value post 1 hour and 3% post 2 hour of exercise (Fahrenholtz et al., 2018).*

NEAT - *Estimated using the absolute daily TEE measure via Polar V800 and calculated via removal of REE during awake period and gross EEE, then divided into awake period minus hours inclusive of net EEE.*

SEE - *Estimated from* RMR_{meas} *and calculated into portion of hours when asleep (RMR / 24 x hours when asleep) (Torstveit et al., 2018).*

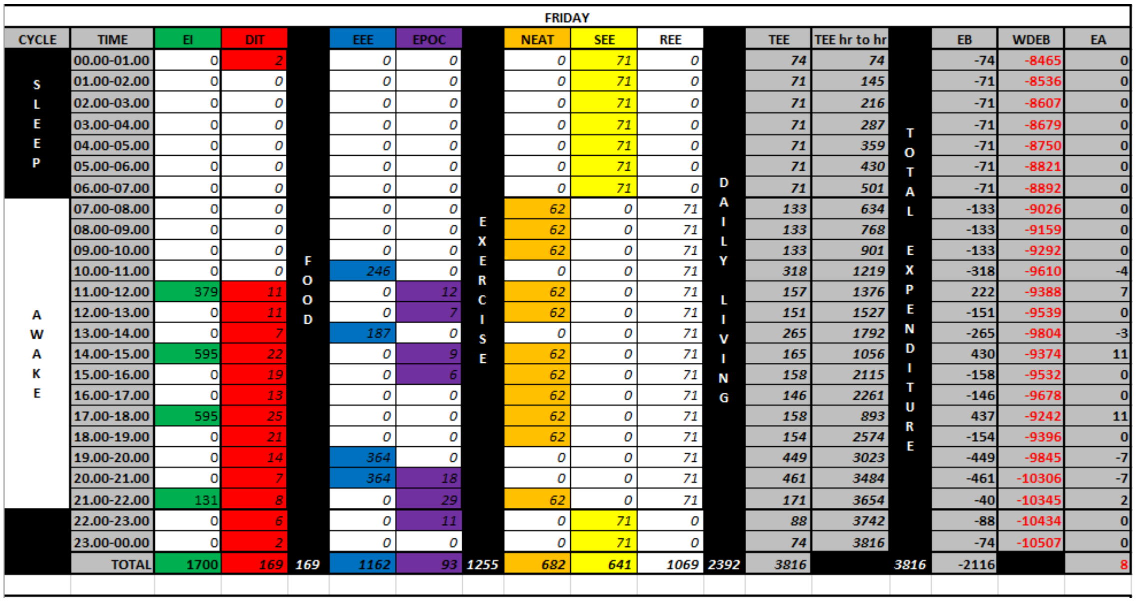
REE - *Estimated from* RMR_{meas} *and calculated into portion of hours when awake (RMR / 24 x hours when awake) (Torstveit et al., 2018).*

TEE - *Calculated from addition of D-EIT/EEE/EPOC/NEAT/SEE/REE for each hour period.*

TEE hr to hr - *Calculated from addition of D-EIT/EEE/EPOC/NEAT/SEE/REE for each hour period and then added to the next hour period (Torstveit et al., 2018).*

EB - *Calculated from EI minus addition of D-EIT/EEE/EPOC/NEAT/SEE/REE for each hour period.*

WDEB - *Calculated from EI minus addition of D-EIT/EEE/EPOC/NEAT/SEE/REE for each hour period and then added to the next hour period (Torstveit et al., 2018)*



FRIDAY																	
CYCLE	TIME	EI	DIT		EEE	EPOC		NEAT	SEE	REE		TEE	TEE hr to hr		EB	WDEB	EA
SLEEP	00.00-01.00	0	2	FOOD	0	0	EXERCISE	0	71	0	DAILY LIVING	74	74	TOTAL EXPENDITURE	-74	-8465	0
	01.00-02.00	0	0		0	0		0	71	0		71	145		-71	-8536	0
	02.00-03.00	0	0		0	0		0	71	0		71	216		-71	-8607	0
	03.00-04.00	0	0		0	0		0	71	0		71	287		-71	-8679	0
	04.00-05.00	0	0		0	0		0	71	0		71	359		-71	-8750	0
	05.00-06.00	0	0		0	0		0	71	0		71	430		-71	-8821	0
	06.00-07.00	0	0		0	0		0	71	0		71	501		-71	-8892	0
AWAKE	07.00-08.00	0	0		0	0		62	0	71		133	634		-133	-9026	0
	08.00-09.00	0	0		0	0		62	0	71		133	768		-133	-9159	0
	09.00-10.00	0	0		0	0		62	0	71		133	901		-133	-9292	0
	10.00-11.00	0	0		246	0		0	0	71		318	1219		-318	-9610	-4
	11.00-12.00	379	11		0	12		62	0	71		157	1376		222	-9388	7
	12.00-13.00	0	11		0	7		62	0	71		151	1527		-151	-9539	0
	13.00-14.00	0	7		187	0		0	0	71		265	1792		-265	-9804	-3
	14.00-15.00	595	22		0	9		62	0	71		165	1056		430	-9374	11
	15.00-16.00	0	19		0	6		62	0	71		158	2115		-158	-9532	0
	16.00-17.00	0	13		0	0		62	0	71		146	2261		-146	-9678	0
	17.00-18.00	595	25		0	0		62	0	71		158	893		437	-9242	11
	18.00-19.00	0	21		0	0		62	0	71		154	2574		-154	-9396	0
	19.00-20.00	0	14		364	0		0	0	71		449	3023		-449	-9845	-7
	20.00-21.00	0	7		364	18		0	0	71		461	3484		-461	-10306	-7
	21.00-22.00	131	8		0	29		62	0	71		171	3654		-40	-10345	2
	22.00-23.00	0	6		0	11		0	71	0		88	3742		-88	-10434	0
	23.00-00.00	0	2		0	0		0	71	0		74	3816		-74	-10507	0
	TOTAL	1700	169	169	1162	93	1255	682	641	1069	2392	3816		3816	-2116		8

Figure 7.5. *WDEB and EA analysis.*

EA was also established both hour by hour and across 24 hours as described by Loucks et al. (2011) (see section 2.8.4), utilising the following calculation: *EA = EI – EEE/LM* of which values were provided by aforementioned data collection and analysis in Chapters 2, 5 and 6. All collected data values were inputted into a bespoke Microsoft Excel (Microsoft UK, Reading, Great Britain) calculative table, to examine daily and weekly differences in absolute and pooled mean data, as highlighted in Figure 7.5.

7.2.8. Overview of Nutritional and Training Intervention

The Athlete's baseline body composition tissues estimated by DXA, were exhibited as 2.2 kg BMC, 54.5 kg LM and 11.3 kg FM respectively. To determine which tissues could be reduced in order for the Athlete to achieve the weight category limit, without detrimental effects on both health and performance (see section 2.8), an estimative calculation of essential FM at the target BM was established as follows: *63 kg BM x 0.06% essential FM = 3.8 kg*. By rounding this value to 4 kg it was acknowledged that the Athlete could lose 7 kg of FM and by subtracting this from baseline BM (72.5 kg), achieve a target BM of 65.5 kg. It was then established that the required additional 2.5 kg reduction could be achieved via acute BM manipulation techniques i.e. reducing gut content, sodium intake, passive dehydration, as described in section 2.7.

Following previous guidelines (Langan-Evans et al., 2011), the Athlete ingested a daily EI allowance equating to approximately RMR_{meas}. This resulted in the following average CHO (3.4 $g \cdot kgLM^{-1}$: 185 g/740 $kcal \cdot day^{-1}$), PRO (2.3 $g \cdot kgLM^{-1}$: 125 g/500 $kcal \cdot day^{-1}$) and FAT (0.9 $g \cdot kgLM^{-1}$: 50 g/450 $kcal \cdot day^{-1}$) macronutrient distributions equating to an average of 1690 $kcal \cdot day^{-1}$. Typical daily feeding distribution/timing and meal composition are presented in Table 7.2. No dietary supplements were implemented (or allowed) throughout the intervention period, to limit any ergogenic effects on subsequent performance based testing results. In the final week leading into the competition, EI was reduced exponentially until the weigh in day, which consisted of low residue/sodium based foods, periodised in line with a scheduled taper of training volume. Fluid consumption was equated at an average of 2 $L \cdot day^{-1}$ and was reduced to 500 ml in the PRE CUT phase, with no fluid on WI (see Figure 7.12). Post WI up until the end of the +1 WK phase the Athlete was allowed to eat and drink ad libitum in order to examine their typical behaviours and the effect these may have on post competitive measurement variables.

Table 7.2. *Typical daily feeding distribution/timing and meal composition.*

MEAL/TIMING	FOOD	QUANTITY (g)	CALORIES (Kcal)	CHO (g)	PRO (g)	FAT (g)
BREAKFAST **7.00 – 10.00am**	***Eggs***	*115*	*150*	*0*	*14.4*	*10.3*
	Mushrooms	*70*	*4.9*	*0.21*	*0.7*	*0.1*
	Onions	*60*	*21.9*	*4.7*	*0.6*	*0.1*
	Baby Spinach	*40*	*6.6*	*0.08*	*1*	*0.2*
Meal Totals			**183**	**5**	**16.7**	**10.7**
LUNCH **13.00 – 14.00pm**	***Grilled Salmon***	*110*	*263*	*0*	*27.1*	*17.2*
	Boiled Soba Noodles	*285*	*205*	*61*	*14.4*	*0.3*
	Tamari Soy Sauce	*18*	*9.7*	*1.6*	*2*	*0.3*
	Steamed Broccoli	*60*	*17.1*	*1.6*	*2*	*0.3*
Meal Totals			**595**	**63**	**54**	**17.8**
DINNER **17.00 – 19.00pm**	***Seared Beef Rump***	*150*	*266*	*0*	*47*	*8.9*
	Sunflower Oil	*5*	*45*	*0*	*0*	*5*
	Boiled Sweet Potato	*270*	*232*	*53*	*3*	*0.8*
	Gravy granules	*100*	*31*	*4.7*	*0.3*	*1.2*
	Boiled Green Beans	*75*	*21*	*2.9*	*1.6*	*0.2*
Meal Totals			**595**	**60.6**	**51.9**	**16.1**
SNACK **Anytime**	***Fruit – Orange***	*160*	*59*	*12.8*	*1.3*	*0.32*
	Chocolate Milk	*400*	*261*	*40*	*14*	*5*
Meal Totals			**320**	**52.8**	**15.3**	**5.3**
DAILY TOTALS			**1693**	**181.4**	**137.9**	**49.9**

The Athlete weekly training schedule consisted of three aerobic and two anaerobic cardio respiratory sessions, two strength & conditioning sessions, three Taekwondo technical/tactical sessions and one sparring session totalling 12-15 hours.wk^{-1} (see Figure 7.6). All Taekwondo based sessions were structured and conducted by the Athlete’s sport specific coach.

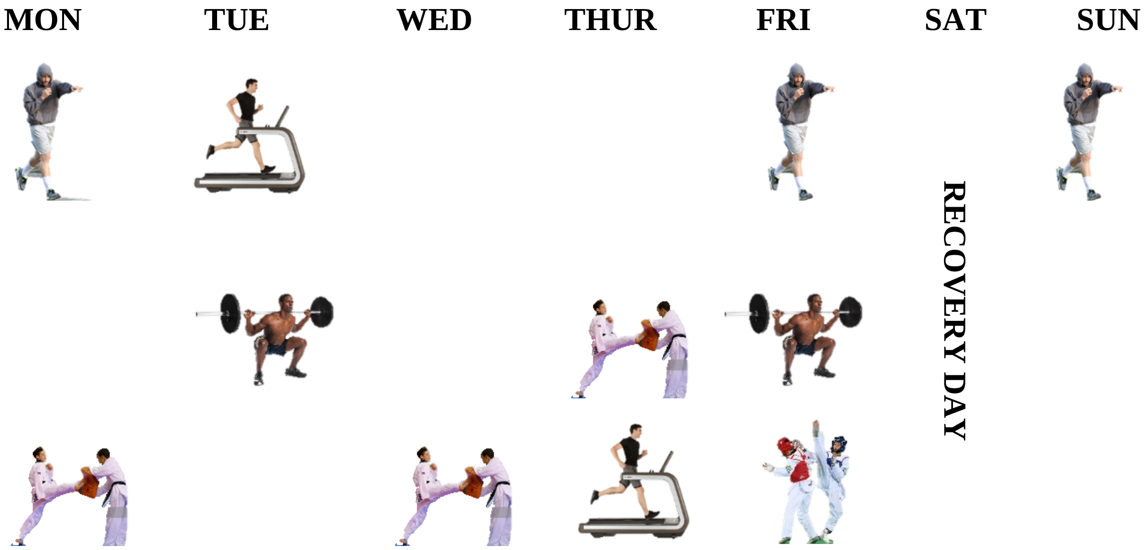


Figure 7.6. *Weekly training distribution and approximate timings.*

Steady state continuous running sessions were conducted in the fasted state, across 45-60 minutes, at a running speed equating to the $\dot{V}O_{2peak}$% corresponding to the highest identified FAT_{max} point. High-intensity interval training sessions were conducted, in three differing activity:recovery structures consisting of 1:1 minutes x 10 intervals and 3:1 minutes x 6 intervals at 120% and 90% of $\dot{V}O2_{peak}$, respectively. Both of these sessions were designed to maximise adaptations to respective an/aerobic systems via mitochondrial volume and density (Bishop et al., 2014; Granata et al., 2018), for maximal fat oxidation during exercise (Achten & Jeukendrup, 2004; Horowitz et al., 1997) and to meet the demands of competition as described in section 2.4.3.

Resistance training sessions were designed based on two mesocycles of general and specific preparation periods. Mesocycle one aimed to increase general strength, via reciprocal increments in volume load and average intensity. Individual sessions were structured into whole body bi and unilateral general strength/speed, concurrently performed in superset with speed/strength exercises. Mesocycle two progressed into an undulating volume load with high average intensity, by adding a combination of maximal strength exercises and speed/reactive strength modalities. In the final week taper leading into competition, no resistance training sessions were conducted and volume load was established for each exercise based on tested MDS 1RM data.

7.3. Results

7.3.1. Overview of Anthropometry Measures, Energy Availability and Within Daily Energy Balance

The Athlete successfully made the weight limit for the elected -63 kg Bantamweight category, recording an official weight of 62.7 kg, representing an overall BM loss of 9.8 kg (13.5%). Measurements of Athlete BM, $\sum_{8SKf}$ and LM/FM/FM% assessed via DXA, inclusive of within participant 90% confidence intervals (90% CI) and smallest worthwhile change (SWC) are shown in Figure 7.7. At -4 WK the Athlete had reduced BM by 4.9 kg with a 17.3 mm reduction in $\sum_{8SKf}$ thickness, occurring at a weekly range of 5.3–6.3 mm in tandem with associated weekly BM losses. Also in this period, FM was reduced by 2.6 kg whilst LM remained stable at 55.0 kg. At -1 WK, the Athlete had further reduced BM by an additional 1.4 kg and $\sum_{8SKf}$ thickness by 6.5 mm. Again there was a 1.8 kg reduction in FM whilst LM continued to remain stable at 54.6 kg. Given the smaller reduction in BM tissues than the previous time course, the associated $\sum_{8SKf}$ thickness reduction was also decreased (ranging from 1.4-3.0 mm). In the final 7 day period leading to WI, the Athlete lost an additional 1.8 kg of BM, concomitant with a further 4.7 mm reduction in $\sum_{8SKf}$. However, FM is only reduced marginally by 0.5 kg, whereas LM was reduced by 1.6 kg at PRE CUT (yet still within SWC) and furthermore by 2.1 kg at WI. Post competition weigh in the Athlete’s BM rose rapidly with a 2.8 kg increase at COMP, a further 2.5 kg 24 hours post competition at +1 D and 3.0 kg to near baseline values at one week post competition +1 WK. $\sum_{8SKf}$ were raised by 2.3 mm on +1 D and by a further 8.1 mm at +1 WK. Despite FM raising marginally by 0.3 kg at +1 D and 0.7 kg at +1 WK, there is a dramatic increase in LM by 5.1 kg in only 48 hours at +1 D and an additional 1.9 kg outside of SWC at +1 WK. Overall given the perturbations in FM and LM tissues, FM% values decrease by 3.4% at -4 WK, 2.3% at -1 WK and then continue to remain stable between 11.0-10.4 at all subsequent time points.

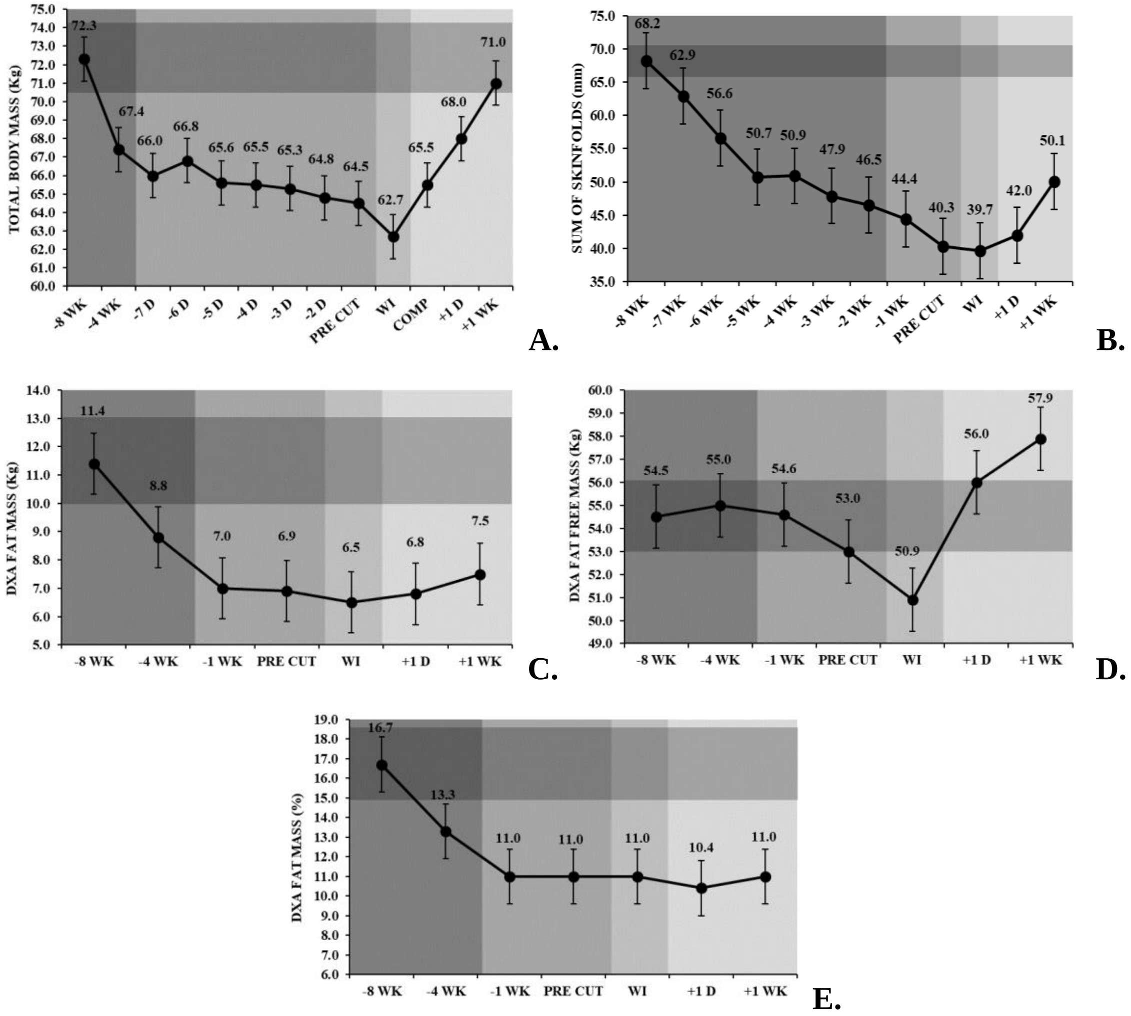


Figure 7.7. *Total BM (A.), $\sum_{SKf}$ (B.), DXA FM (C.), DXA LM (D.) and DXA FM% measurements inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC).

The Athlete was classified as being in LEA throughout the entire intervention period, with average values ranging between 6-30 kcal·kgLM·day^{-1} in -8 WK to -1 WK phases and negative values (-7 to 9 kcal·kgLM·day^{-1}) in the final week leading into the competition (-1 WK/PRE-CUT/WI), representing a mean of 20 kcal·kgLM·day^{-1}. EA was rescued to average values ranging between 54-100 kcal·kgLM·day^{-1} in the post competitive +1 WK phase (see Figure 7.8).

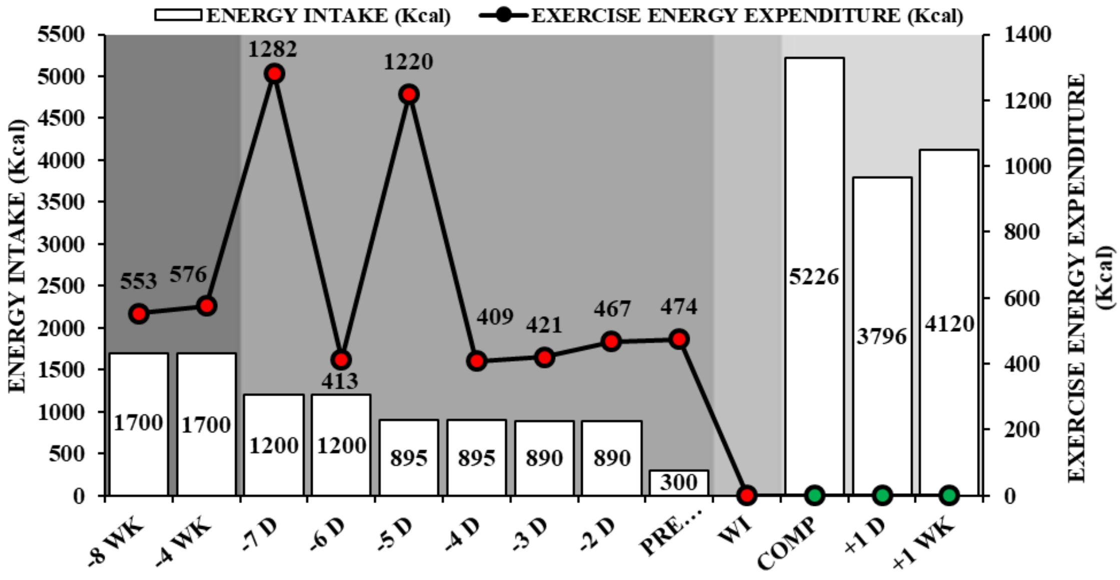


Figure 7.8. *EI and EEE highlighting energy availability status throughout the intervention and recovery period.*

(Grey zones denote differing time periods; Red markers indicate EA <30 kcal·kgLM·day^{-1}; Green markers indicate EA >45 kcal·kgLM·day^{-1}).

WDEB assessment highlighted that the Athlete was in a net hour by hour catabolic energy deficit across the entire intervention period, due to average EI's of 11,900 kcal·wk^{-1} parallel to average TEE's of 22,000 kcal·wk^{-1}. WDEB values averaged -13,200 kcal·wk^{-1}, which resulted in an accumulated -105,000 kcal·wk^{-1} deficit at the conclusion of the intervention period. In the post competitive phase this deficit continued to increase, albeit at a slower rate, resulting in a final WDEB value of -106,000 kcal·wk^{-1} in the final week of measurement, despite an exacerbated refeeding period (EI equalling 33,000 kcal·wk^{-1}) and complete cessation of training (see Figure 7.9).

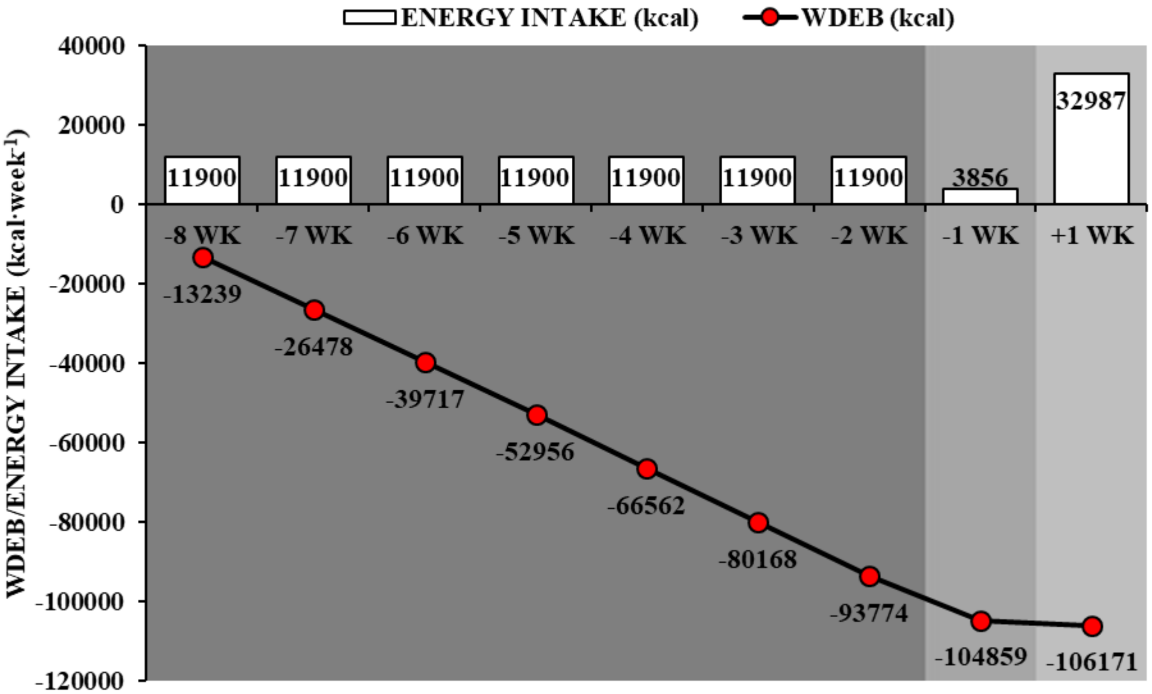


Figure 7.9. *WDEB and EI throughout the intervention and recovery period (Grey zones denote differing time periods; Red markers indicate negative WDEB).*

7.3.2. Overview of Intervention on Athlete Wellness, Sleep and Training

Throughout the intervention the Athlete’s DWBS were >15 and they completed all assigned sport specific, cardiovascular and resistance training sessions in order to meet the designated training load as highlighted in Figure 7.10.

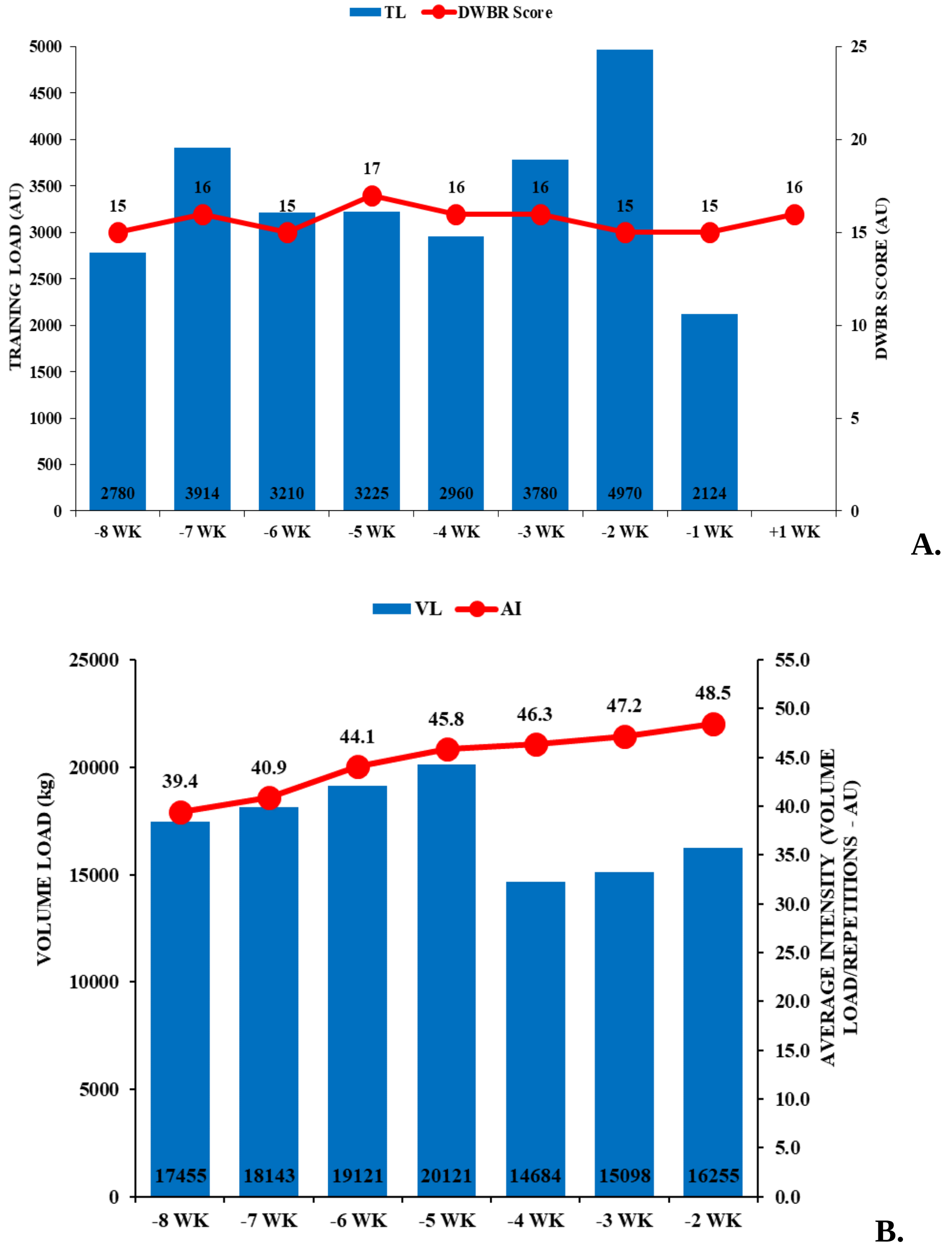


Figure 7.10. *Perceived load and wellness scores (A.) with S&C training loads and intensities (B.) throughout the intervention*

Across the intervention period there were no negative associations exhibited between DWBS, EI or EA and the Athlete's sleep duration/latency/efficiency, fragmentation index or total activity score, with only duration and efficiency being effected by overall training load (volume and density) as highlighted in Figure 7.11.

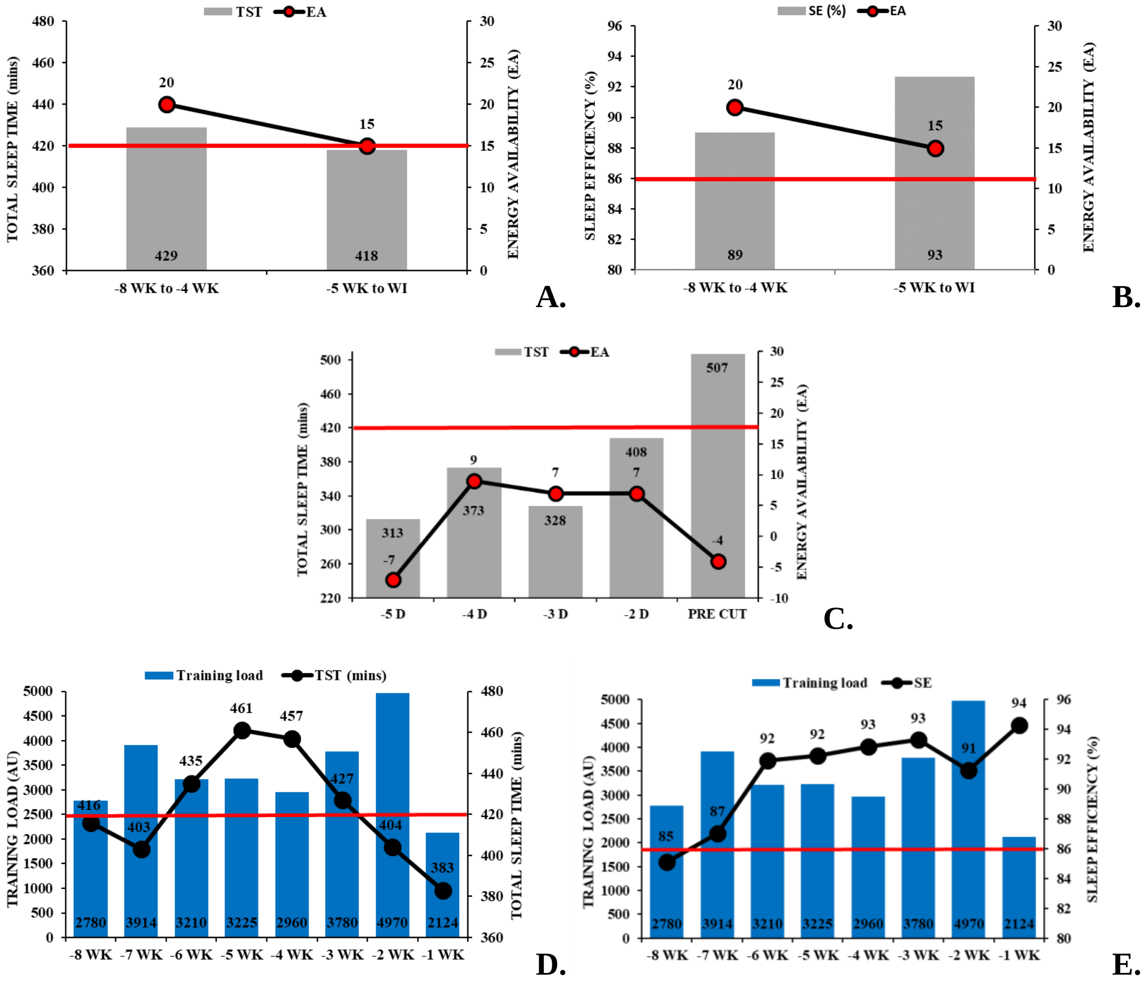


Figure 7.11. *Effects of EA and training load on total sleep time (A. -8 WK to WI; C. final week taper; D. -8 WK to -1 WK) and efficiency (B. -8 WK to WI; E. -8 WK to -1 WK) parameters throughout the intervention*

(Red markers indicate EA <30 kcal·kgLM·day-1; Red lines indicate minimum threshold for total sleep time and sleep efficiency).

Hydration status assessed by U_{osm} highlighted that the Athlete was dehydrated across all time points according to guidelines in Table 2.8, yet upon assessment of P_{osm} values, this was only confirmed during the WI phase. When P_{osm} was examined in parallel with markers of blood Na^+, the Athlete can be diagnosed with moderate hypohydration and hypernatremia at the WI phase, however this is rescued after a period of rehydration within 24 hours post competition at +1 D (See Figure 7.12 and 7.15).

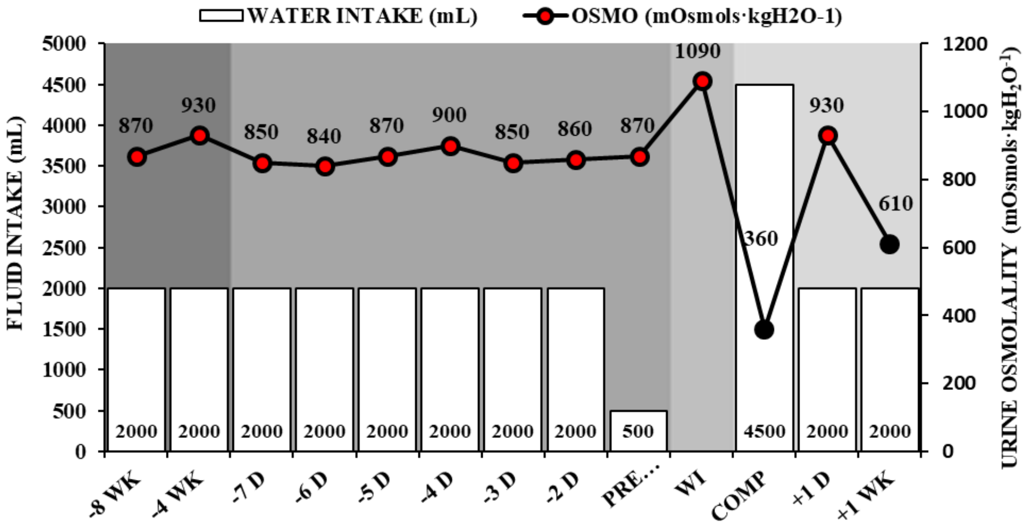


Figure 7.12. *Fluid intake and U_{osm} throughout the intervention and recovery period (Grey zones denote differing time periods; Red markers indicate Uosm >700 mOsmols·kgH2O−1).*

In all semi structured interviews and despite probing, the Athlete made no comments in regards to hunger or gastrointestinal distress and reported no illness or injury incidences.

7.3.3. Assessment of RED-S Consequences on Markers of Health and Performance

Metabolic

Assessment of the Athlete’s metabolic status is highlighted in Figure 7.13. Throughout the intervention, there is a transient reduction in RMR_{meas} values by -37 kcal·day^{-1} at -4 WK, -72 kcal·day^{-1} at -1 WK and an exacerbated decrease in only a 4 day period to -149 kcal·day^{-1} at PRE CUT, representing an overall reduction of 258 kcal·day^{-1}. However, this recovers within the post competition period by an increase of 648 kcal·day^{-1} at +1 WK, representing a 390 kcal·day^{-1} increase from baseline. Examining differences between RMR_{meas} and RMR_{pred}, AT is exhibited as -36 kcal·day^{-1} at -4 WK, -99 kcal·day^{-1} at -1 WK and again an augmented decrease of -213 kcal·day^{-1} at PRE-CUT. When examined in tandem with RMR_{ratio}, there is also a gradual decrease across the intervention period, however with all values above <0.90 except for at PRE CUT, highlighted at an RMR_{ratio} of 0.87.

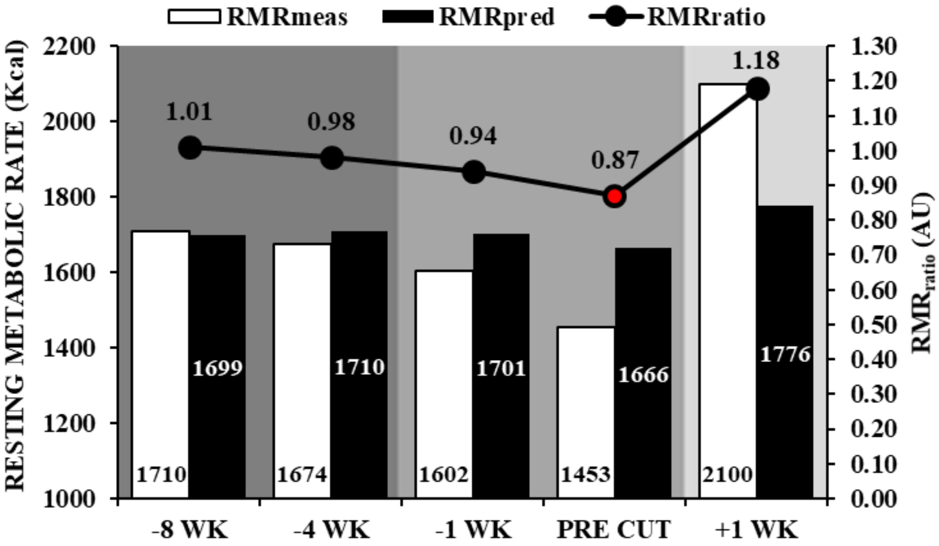


Figure 7.13. *RMR and ratio measurement throughout the intervention and recovery period*

(Grey zones denote differing time periods; Red markers indicate RMRratio <0.90 representing energy deficiency).

Endocrine/Haematological

Endocrine profiles for testosterone, cortisol, insulin, IGF-1, LH, FSH and SHBG, inclusive of 90% CI and SWC are all highlighted in Figure 7.14. Throughout all tested periods during the intervention, there is a gradual reduction in testosterone profile reaching outside of SWC at -1 WK and reference levels at WI, yet this is quickly rescued at +1 D and to near baseline levels at +1 WK. Cortisol profile levels remain stable between an acceptable reference range of 407-571 mmol/L at all time points. Insulin profile remains consistent throughout the intervention period between 26-21 pmol/L and then sharply increases to 142pmol/L outside of SWC and reference levels at +1 D and then reducing to a level above baseline at +1 WK. IGF-1 and LH profiles both marginally reduce across the intervention period to below SWC in -1 WK to +1 D, yet remain above acceptable reference levels and are rescued to baseline +1 WK. FSH remains within SWC and reference levels at all time points. SHGB profile increases beyond SWC at -4 WK, raising at each subsequent time point throughout the intervention and is the only other endocrine marker outside reference range levels at WI, but is reduced to below reference and subsequent baseline levels at +1 D and +1 WK.

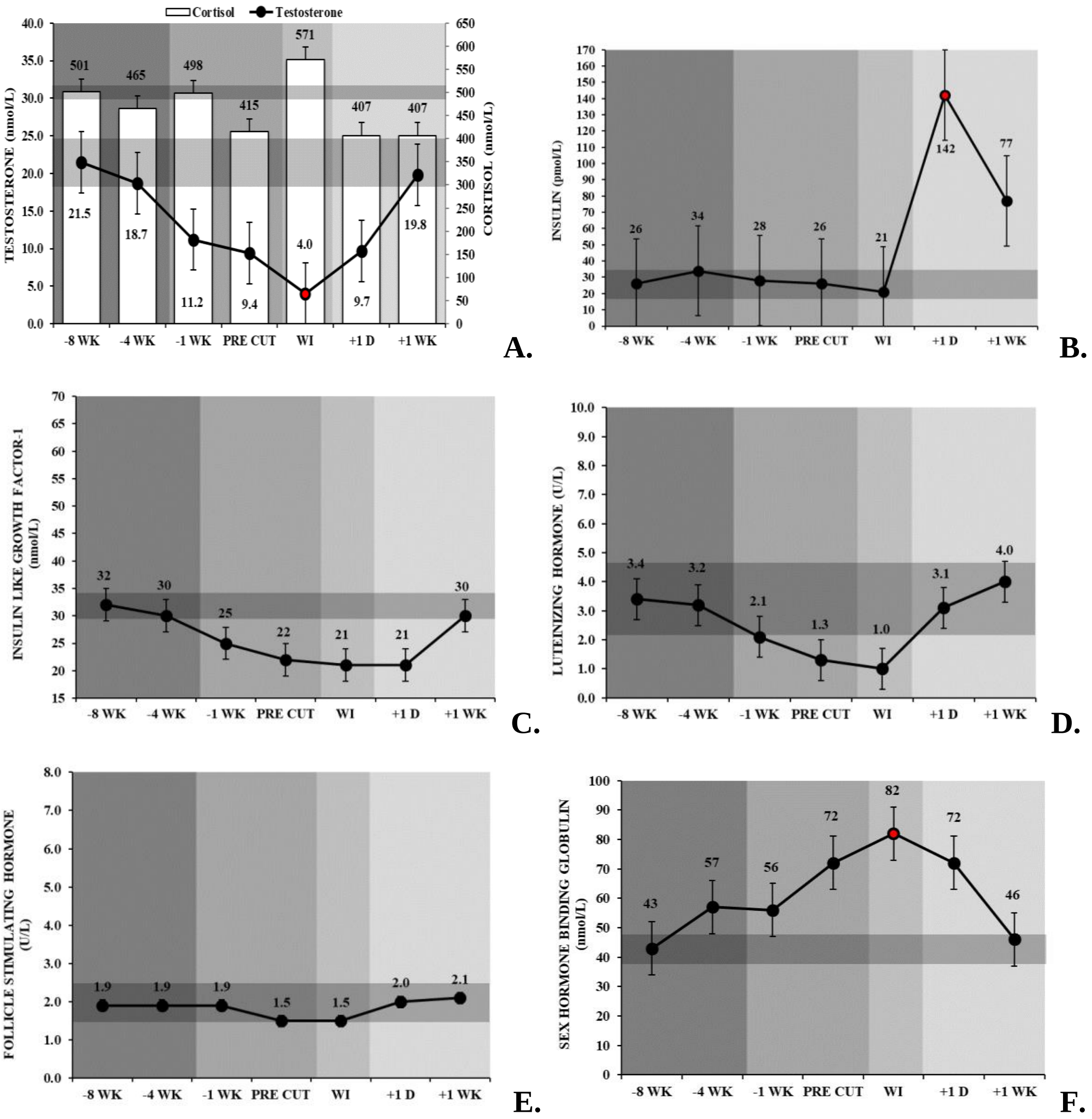


Figure 7.14. *Hypogondal axis endocrine responses for testosterone and cortisol (A.), insulin (B.), IGF-1 (C.), LH (D.), FSH (E.) and SHBG (F.) inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Red markers indicate values outside of normal reference ranges).

P_{osm} and Na^+, urea, creatinine electrolyte profiles as markers of renal function inclusive of 90% CI and SWC, are highlighted in Figure 7.15. P_{osm} elevates throughout the intervention rising outside of SWC at -4 WK, yet does not reach above reference levels until WI, before subsiding at +1 D to plateau above baseline at +1 WK. Na^+ remains within SWC until PRE-CUT, where there is a sharp elevation above reference levels at WI, which is subsequently rescued +1 D and +1 WK. Urea and creatinine also consistently increment above baseline ascending outside of SWC at PRE-CUT, and urea values, which are above an acceptable reference range at WI. Creatinine stays within the reference range at WI and steadily reduces to within SWC at both +1 D and +1 WK, whereas urea declines at +1 D to within SWC and then sharply rises again at +1 WK.

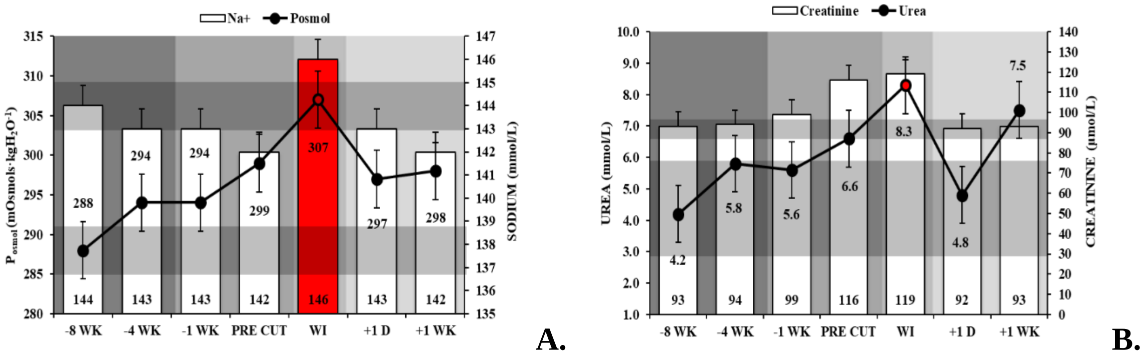


Figure 7.15. *Renal function profiles of plasma Na^+/P_{osmol} (A.) and urea/creatinine (B.) concentrations inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Red markers/bars indicate values outside of normal reference ranges).

Liver function markers of ALB, GLOB, total protein and bilirubin inclusive of 90% CI and SWC, are highlighted in Figure 7.16. ALB biomarkers remain above reference levels at all time points across the intervention and post +1 D and +1 WK periods. Conversely, GLOB remains stable, within an acceptable reference level, albeit with values outside of SWC other than at baseline and WI. Given the fluctuations in ALB and GLOB values, total protein remains elevated within the intervention period and outside an acceptable reference range at WI, before reducing in the post competitive period below baseline SWC at both +1 D and +1 WK. Bilirubin is raised above reference range levels across the intervention period, with a transient decrease below SWC at -4 WK until PRE CUT and a marginal raise at WI, before dramatically decreasing further to reference levels post competitive period at +1 D and +1 WK.

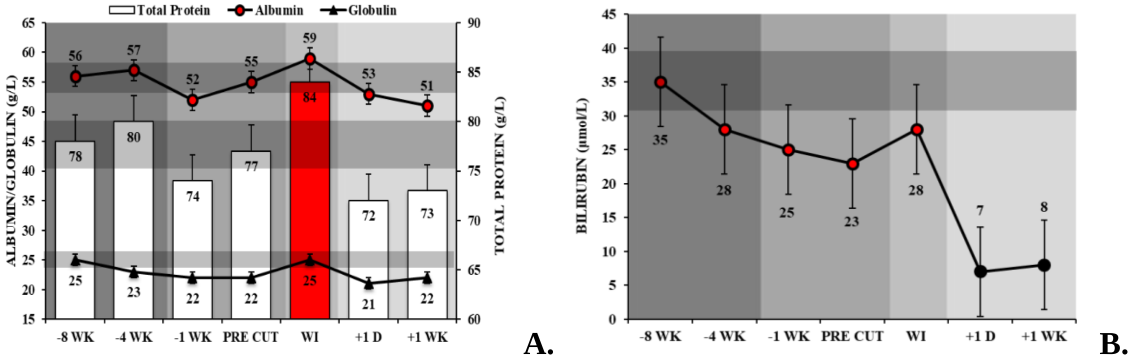


Figure 7.16. *Liver profiles of ALB, GLOB, total protein (A.) and bilirubin (B.) inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Red markers/bars indicate values outside of normal reference ranges).

Lipid profiles for total cholesterol, HDL, LDL and triglyceride inclusive of 90% CI and SWC, are highlighted in Figure 7.17. Total cholesterol, HDL and LDL increase exponentially throughout the intervention period and despite remaining within the respective SWC, with the later reaching outside of reference ranges at WI, this additionally elevates total cholesterol level above an acceptable range. All markers are quickly rescued to normal reference levels post competition at +1 D, before being elevated again, yet still within reference ranges at +1 WK. Triglyceride levels remain stable across the intervention period, yet exhibit a sharp increase in the post competitive phase outside of SWC, although still within normal reference ranges.

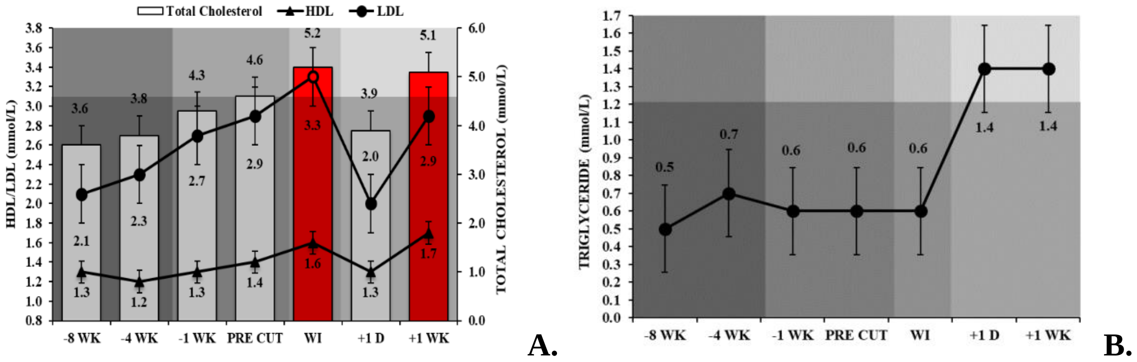


Figure 7.17. *Lipid profiles of HDL/LDL, total cholesterol (A.) and triglycerides (B.) inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Red markers/bars indicate values outside of normal reference ranges).

Bone Health

Bone metabolism biomarkers of β-Ctx, P1NP, Ca^+, phosphate and PTH inclusive of 90% CI and SWC, are highlighted in Figure 7.18. β-Ctx is within SWC, yet above normal reference ranges at all time points, with a steady increase from baseline to a peak high value at +1 WK. P1NP is also all above the highest reference range at all time points, with an sharp increase beyond SWC from -8 WK to -4 WK, followed by a transient decrease in the period leading into the competition at -1 WK, PRE CUT and back to within SWC at WI. This is then followed by an increase above baseline post competition at + 1D and +1 WK. The P1NP/ β-Ctx ratio is above 1.0 at all phases, ranging from 1.2 at WI to 2.2 at + 1D. Both Ca^+ and phosphate remain within both SWC and normal reference ranges at all time points, albeit with a sharp rise in phosphate at +1 WK. PTH is within normal reference ranges throughout the intervention and post competitive periods, however rises steadily beyond SWC at -4 WK and throughout all following time points.

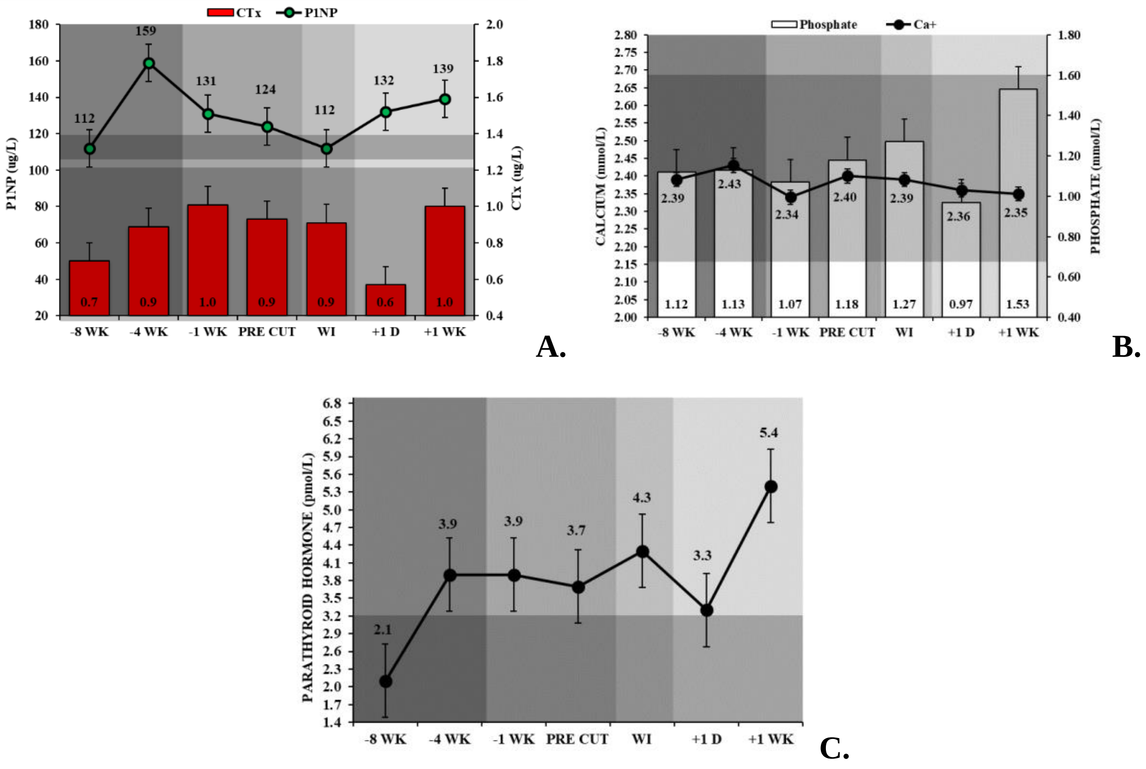


Figure 7.18. *Bone turnover markers for β-Ctx/P1NP (A.), Ca/Ph (B.) and PTH (C.) inclusive of within 90% CI throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Red bars indicate high bone reabsorption values; Green markers indicate high bone formation values).

Cardiovascular

LVEDV/RVDAREA structure, EF/RVFAC function and CO/HR measured via ECG/echocardiography are presented in Figure 7.19. There were no major changes in either structure or function of the right and left ventricles, with only a hypertrophic response of the LVEDV exhibited in PRE CUT. Both CO and HR reduce transiently from baseline at -8 WK to PRE CUT with a rapid increase in both measures within 24 hours at WI which plateaus in the +1 WK post competitive period.

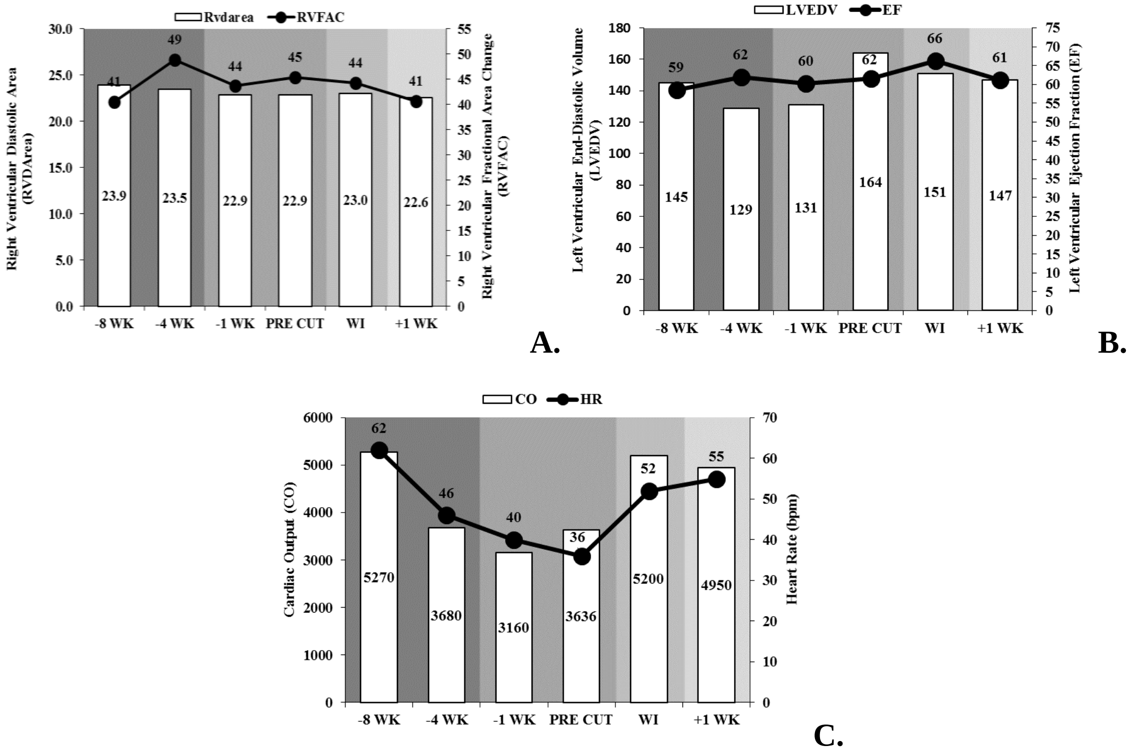


Figure 7.19. *ECG and electrocardiogram measurements throughout the intervention and recovery period*

(Grey zones denote differing time periods; In graphs A & B bars represent cardiac structure and lines cardiac function).

Psychological

POMS and TMD are displayed in Figure 7.20. There were no major differences in either measurement throughout all time points, other than at WI, where there is a reduction in POMS and elevated TMD above baseline. This is quickly returned to an iceberg POMS profile and reduced TMD 24 hours later at COMP and for all subsequent post competitive phases.

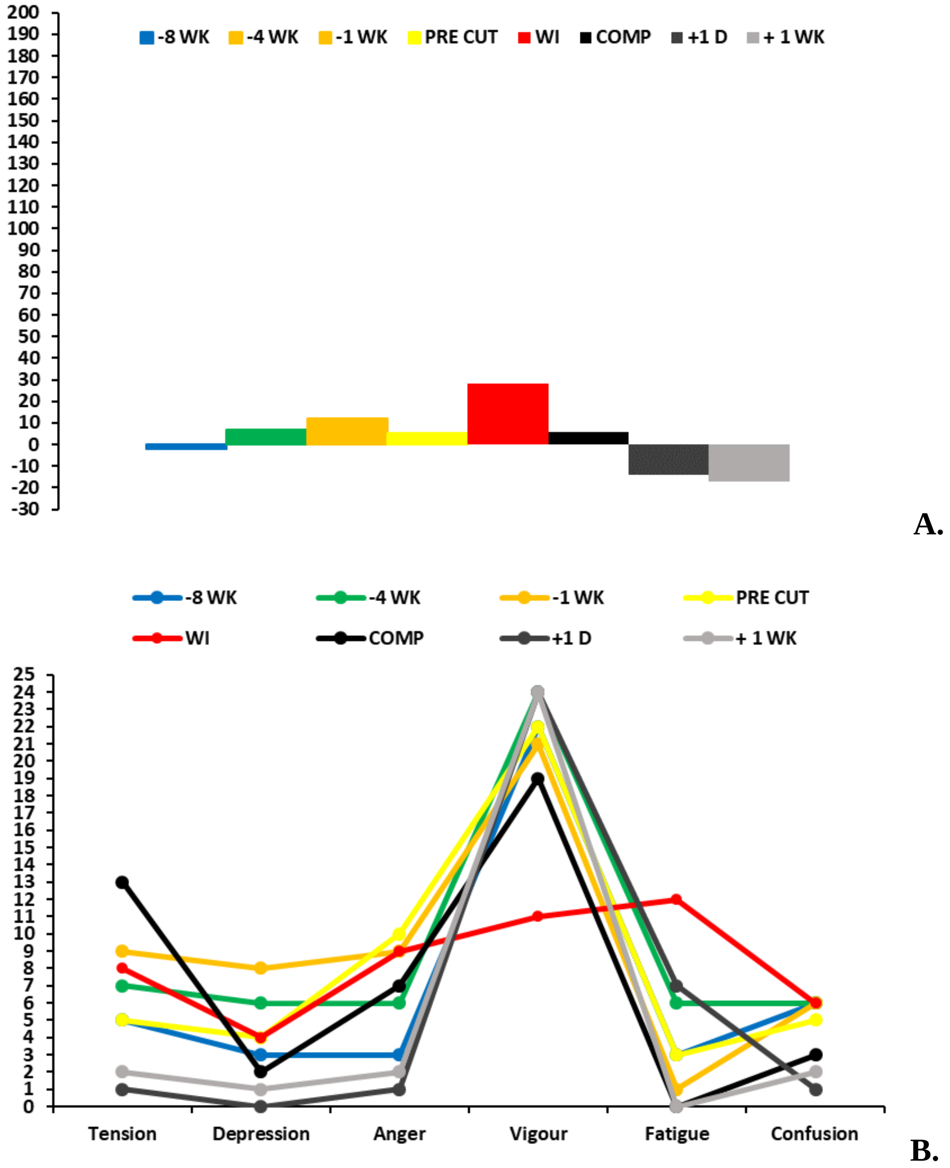


Figure 7.20. *POMS and TMD throughout the intervention and recovery period (Coloured bars and lines denote differing time periods)*

Excerpts ascertained from semi structured interviews, highlight how prior to the intervention at -8 WK baseline, the Athlete describes their *fear* of losing such a large volume of BM:

'I'm scared, I'll be honest with you. I've never lost or looked to lose an amount as high as this.'

However when re-interviewed at -4 WK the Athlete discusses their *elation* at how the process is going:

'I've said this to my family and friends, it's the best I've felt, like, on a diet, making weight process type of thing. Physically I feel probably in the best shape of my life and mentally I'm happy through the eating and training that I'm doing, everything.'

Their *disbelief* in successfully achieving their usual weight category for a preparation competition without the need to engage in previously employed dehydration methods:

'Shocked and happy. It's the first time I've never had to dehydrate or crash. It was all natural…I mean fuck me I ate prior to weigh in I still don't know how that is even possible?!'

And their new *perceptions* of nutritional practice:

'…with training it's definitely the timing of the feeds, the food I'm eating, I can perform a lot better for a lot longer during training periods. I think the performance shown at the weekend, it does have an impact. On competition day I ate through the day, I had breakfast, had some dinner and yeah, performance was spot on…I don't need to be afraid of food.'

In the final week prior to the weigh in at -1 WK, the Athlete discusses their feelings leading into the weigh in and their continued *anxiety* over their potential in making the required weight category:

'I'd say my behaviour before I've done this with you guys was worse than this period, like, because beforehand my mood would be a lot worse and I wouldn't be as determined, I'd slip up on my diet, snack here, snack there, without telling anyone…I still have that anxious feeling "am I going to make the weight?" but I'm a lot more confident from where I am now from where I was 3-4 weeks ago.'

The Athlete also compares this period to previous practice:

'I wouldn't say it's been easy, the training has been tough but it's been easier than what I was used to do beforehand. It's structured a lot better, it's not as rushed, I don't feel as drained, I'm still full of energy, still training hard…I didn't think it would be possible to get my weight this low and still feel as fit and fast and full of energy as I am now. I didn't think that was possible…I'm not just focussed on making the weight all the time now to…It's optimising performance as well.'

In the PRE CUT phase the Athlete describes their *realisation* and *confidence* in that they are going to achieve the targeted weight category, with also a renewed sense of *focus* not typically personified in previous preparations:

'Definitely I'm more towards making it than not. I'm more confident that I am going to make it but I'd say my head's sort of in two places at the minute, like, so making that weight but it's probably the most focussed I've been on fight day this close to a competition.'

They describe their previous *fears* and *thoughts* on how they perceived the intervention would affect their health and performance:

‘The thought of losing that amount of weight, it was 9-10 kilos, it was scary. I haven’t been that weight for 2-3 years at least, so to go from that amount of time to then making that weight again I was thinking “I’m gonna be a wreck, I’m not going to make it, I’m gonna feel like crap in and out of the ring” but it’s been the complete opposite.’

And finally a sense of *accomplishment*:

‘I feel like I’ve really accomplished, it’s near enough emotional, that I’ve nearly made the weight and we are so close to making it. I wouldn’t have thought I’d have got half this or half the way.’

Finally post WI the athlete describes their *exhilaration* in meeting the targeted weight category goal:

‘I’m over the moon, to be honest, yeah, as I say, still shocked, still think it’s unbelievable. I mean just to see it really, from where we were at the start and thinking “no, I’m not going to make this” and stepping on the scales today actually .3 under 63, it’s overwhelming.’

Performance

Ballistic and Reactive strength EUR/RSI profiles ascertained from CMJ/SJ and BDJ are highlighted in Figure 7.21. From baseline at -8WK until -1 WK there is an 8-11% reduction in SJ/CMJ and BDJ JH. Despite this, both EUR and RSI both increase by 3% and 19%, respectively, given transient fluctuations in SJ/CMJ JH and reductions in GCT.

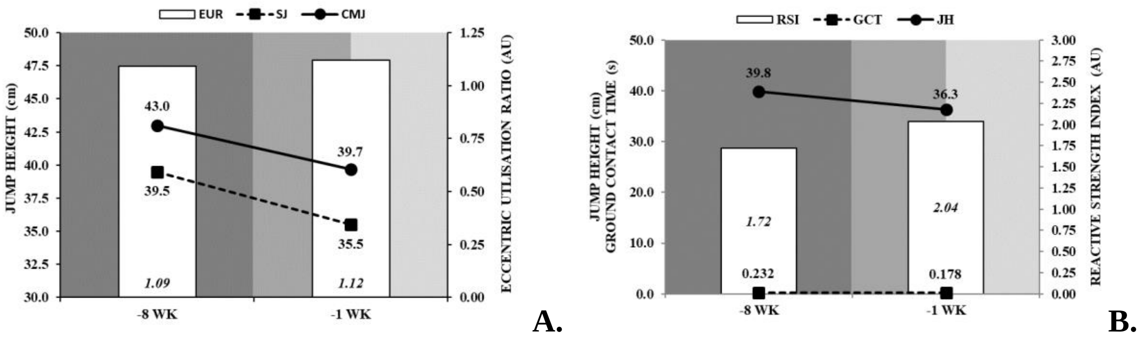


Figure 7.21. *CMJ/SJ and EUR (A.) with BDJ/GCT and RSI (B.) scores throughout the intervention.*

(Grey zones denote differing time periods)

MDS profile via both bench press and squat 1RM tests inclusive of 90% CI and SWC, are shown in Figure 7.22. At all measured time points, both upper and lower MDS increased both absolutely by 6-9% and relatively by 18-19% (increasing outside of SWC), despite reductions in BM throughout the intervention (*n.b. bench press was not completed at +1 WK, due to the Athlete fracturing their left hand in competition*).

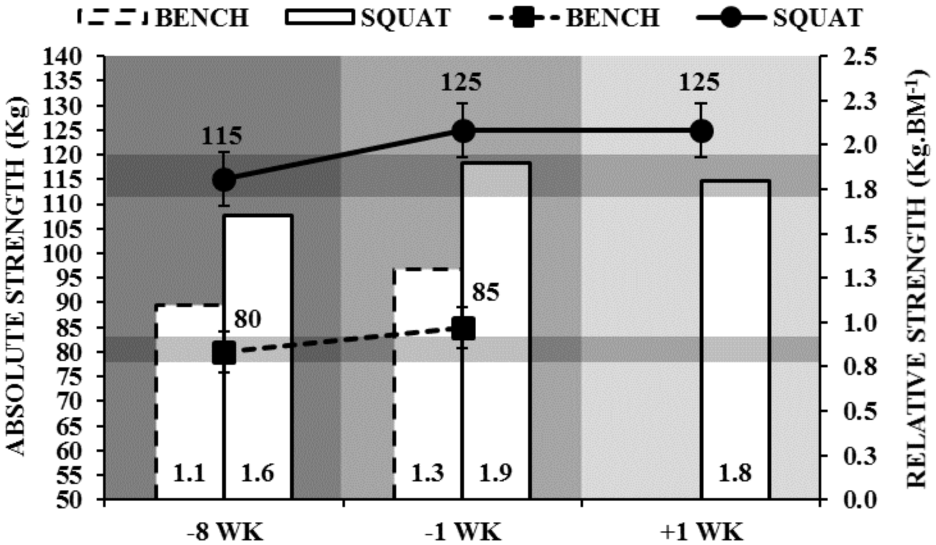


Figure 7.22. *Absolute and relative upper and lower MDS scores throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Absolute values include within 90% CI's).

MDP upper and lower F/V profiles are highlighted in Figure 7.23. From -8 WK at baseline to -1 WK, MDP increases in both upper absolute and lower relative force/velocity and power curve profiles.

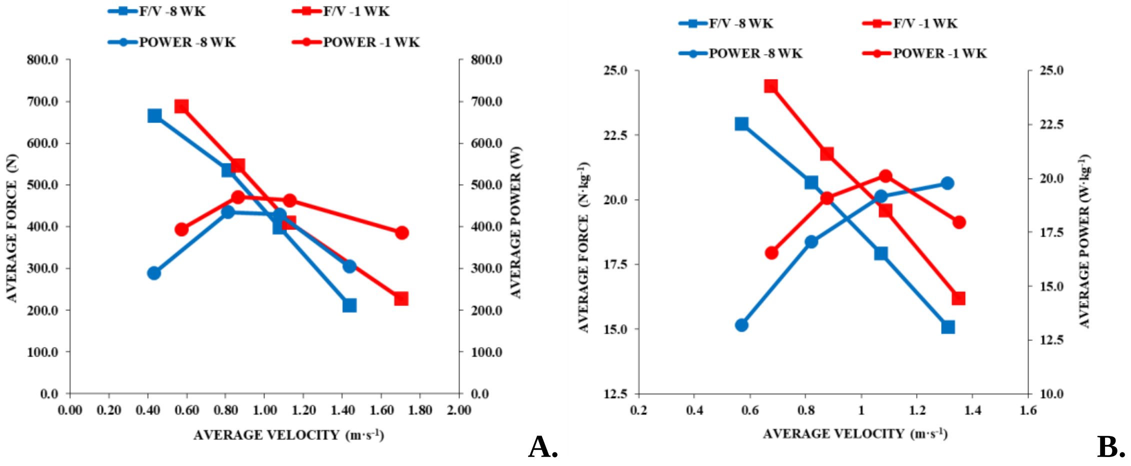


Figure 7.23. *Upper (A.) and lower (B.) force/velocity and power profile MDP throughout the intervention*

(Coloured lines denote differing time periods).

Aerobic cardiorespiratory capacity measured by maximal oxygen uptake inclusive of 90% CI and SWC, is highlighted in Figure 7.24. At all time points throughout the intervention, both relative and absolute $\dot{V}O_{2peak}$ values increase exponentially, representing a 19% and 13% improvement, respectively. Absolute values are maintained at +1 WK, yet this decreases relatively in relation to increases in BM post competition. However despite this, relative values remain elevated above baseline SWC at all time points. There was also an increase in the Athlete's FAT_{max} peak profile from 0.62 $g\cdot min^{-1}$ at 44% to 0.72 $g\cdot min^{-1}$ at 60% $\dot{V}O_{2peak}$ from -8 WK to -1 WK. However, there was a dramatic reduction from baseline in +1 WK represented by 0.42 $g\cdot min^{-1}$ at 30% $\dot{V}O_{2peak}$.

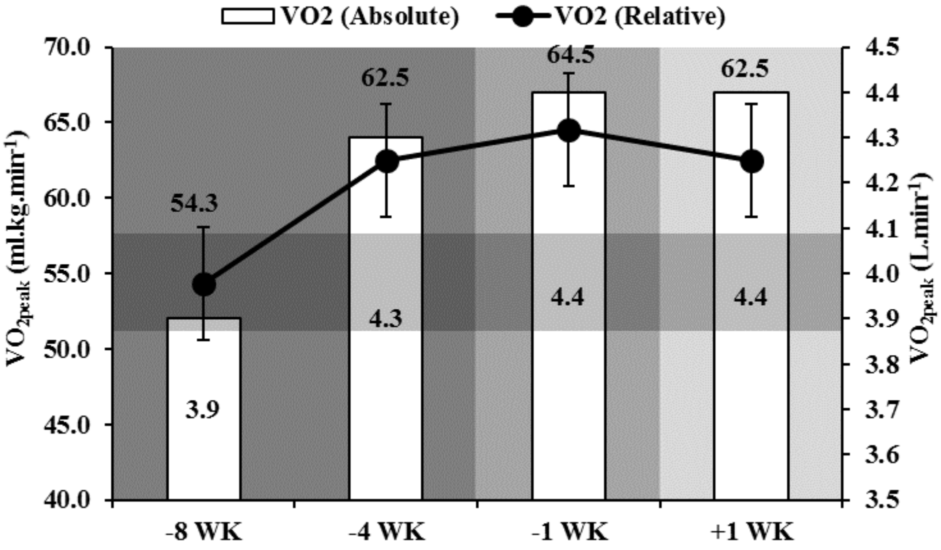


Figure 7.24. *Absolute and relative aerobic cardiorespiratory capacity measurements throughout the intervention and recovery period*

(Grey zones denote differing time periods and shaded areas represent SWC; Relative values include within 90% CI's).

The Athlete won the gold medal at the championships, after successfully winning 4 matches by scores of 24-6 in the round of 16, knockout in the quarter-finals, 20-5 in the semi-finals and 22-4 in the final, successfully qualifying for his elected weight category to represent the national team at the 2018 European University Games.

The Athlete had the following final reflections in relation to the whole intervention and his final achievement:

'Physically I've never felt so ready. I felt like, you know, this is what the whole past 8 weeks has been leading up to. As ready, best prepared as I could be…I'd say I was slightly tired from the dehydration but again, there were just no negatives from the weight loss…it's the second competition where I've actually eaten throughout the day now. Before then I've never really eaten until after fights but yeah, second competition whilst eating and felt amazing. Nutritional habits were good I'd say…I can't believe I made the weight and I can't believe I took the gold…this is the way all fighters should prepare for competition…I cannot thank you all enough, you've changed my life.'

7.4. Discussion

The aim of this study was to examine the effect of a periodised nutritional and training intervention on symptoms of RED-S consequences in an international standard Taekwondo athlete while making weight for competition. This investigation represents the first time a periodised nutritional and training intervention, has been utilised to aid an international standard Taekwondo athlete in achieving a target weight category and only the second time in combat sports (Morton et al., 2010). Additionally, due to previous research (see section 2.8.4) alongside the findings of Chapters 5 and 6, it was possible to also establish measurements of EA and WDEB, whilst concomitantly assessing the potential for RED-S consequences, which have never been previously characterised in this demographic.

The dietary modulation in this study was to meet the minimal energetic equivalent of the Athlete's RMR at 1700 kcal·day^{-1}, in line with previous guidelines (Langan-Evans et al., 2011), which have been successfully implemented in a number of other case/cohort studies in jockeys (Wilson et al., 2012; Wilson et al., 2015) and in professional boxing (Morton et al., 2010). Whilst below many recommended nutritional guidelines and resulting in an average EA of 20 kcal·kg·LM·day^{-1}, this case study adds to the emerging evidence that this may represent a critical threshold of EI to support primary physiological functions, independent of an increase in EEE and/or EA status. Additionally, it appears that the prescribed macronutrient intakes support the guidelines of Sundgot-Borgen et al. (2013), are key in preserving LM whilst reducing FM (as described in section 2.8.5) and serve to 'fuel for the work required' (Impey et al., 2016). During the first seven weeks of the intervention this EI and EA appears to maintain both RMR_{ratio} and LM at homeostatic levels, albeit with minor transient reductions, which appear to be linked to the time spent in energetic deficit (Keys et al., 1950; Muller et al., 2015). Intriguingly, it is not until the week prior to WI, when there is a dramatic reduction in EI (1200-300 kcal·day^{-1}) and EA (<7 to 9 kcal·kg·LM·day^{-1}), that RMR_{ratio} becomes severely suppressed, accompanied by an exacerbation of AT in a period of only 5 days. Whilst these adaptations have been linked to parallel reductions in the neuroendocrine hormones of the hypothalamic-gonadal-axis axis (Elliott-Sale et al., 2018; Rosenbaum & Leibel, 2010), only testosterone and SHBG go outside of normal reference ranges, yet are quickly rescued within 48 hours after a period of refeeding, in agreement with previous investigations examining this paradigm (see section 2.8.5).

Despite liver function biomarkers which are concernedly high throughout the intervention period, previous evidence highlights that hyperalbuminemia has been associated with higher PRO intakes and intense exercise (Mutlu et al., 2006), whilst hyperbilirubinemia has been linked to dramatic changes in exercise volumes of athletic demographics (Witek et al., 2017). A greater cause for concern are both the renal function and lipid profile biomarkers, particularly in the PRE CUT and WI phases. The rise in plasma Na^+, concomitant with increases in urea, is indicative of hypohydration/hypernatremia and whilst these levels would not serve to cause acute kidney injury, they are still markedly high considering the limited amount of BM loss via dehydration (2.8%). Additionally, with an alarming increase in both LDL and TC, examined in parallel with 24 hour increases in both HR and CO, this highlights the dangers, in particular relating to all cause mortality of hyperthermia during excessive dehydration (>5% BM). However, despite these changes, both cardiac structure and function remain unchanged, indicating a nominal effect of either LEA or dehydration on this factor of RED-S.

Whilst bone reabsorption measured via β-Ctx is above athletic reference ranges at all-time points, this appears to be offset by levels of bone formation measured via P1NP, which maintains a positive ratio of bone turnover (>1.0). This supports recent hypotheses that the osteogenic stimulus of the Athlete's training regime may have offset the negative effects of LEA status (see section 2.8.5). However, it is interesting to note that during the final -1 WK to WI phase, when the energetic deficit is increased, there is a steady decline in P1NP, yet this coincides with when the Athlete's training volume was gradually reduced to taper into the COMP phase. This hypothesis can be supported by the steady increases in PTH throughout the intervention period, which reach levels 157% above baseline in the post competitive phase at +1 WK. This interaction plays on maintaining homeostatic levels of Ca^+ and phosphate, with the large increases in the latter during +1 WK, also likely regulated by a 104% increase in dietary phosphorus during refeeding.

There were no apparent negative associations of either POMS or TMD during the entire intervention period, given the consistent iceberg profiles, which is in support of other case/cohort research studies examining iterations of this intervention in jockeys (Wilson et al., 2012; Wilson et al., 2015) However, this does conflict to other investigations in body builders (Rossow et al., 2013), yet these psychological disturbances were displayed over more protracted periods (>6 months) in comparison to this intervention. It should be noted that there were decreases in vigour, parallel to increases in tension, fatigue and confusion during the WI period, although this has already been well characterised during A/RWL induced dehydration (see sections 2.6 and 2.8.5). Despite this, the quantitative responses of the Athlete during all phases, highlight that there are no perceived negative associations at this time point, with consistent reference to how the intervention was a major improvement on previous practice, whilst also feeling the most psycho-physiologically conditioned they have ever been in their competitive career.

There were no negative associations of RED-S consequences on all tested parameters of performance with the Athlete well above all normative values described in section 2.3. Despite reductions in JH via CMJ/SJ/BDJ, there were consistent increases in both EUR and RSI, tantamount to major improvements in ballistic and reactive strength, which were target components of the S&C training programme and are crucial for Taekwondo sporting performance (see section 2.3.1). MDS and MDP measured both relatively and absolutely, were increased throughout the intervention period regardless of LEA status, conversely to studies on male body builders (Rossow et al., 2013) and elite endurance athletes (Tornberg et al., 2017), although yet again these were in prolonged periods and in a female cohort so make comparison difficult. There were also no negative associations of RED-S on the Athlete's aerobic cardiorespiratory performance, again measured both relatively and absolutely. This is in agreement with a number of studies highlighting that this appears to remain unaffected by LEA status (Tornberg et al., 2017) and also in individuals with eating disorders (El Ghoch et al., 2013). All of these results conflict with the emerging idea of RED-S consequences on performance (Ackerman et al., 2018; Mountjoy et al., 2018), yet it should be noted that there is a paucity of research in this area, with most studies identifying this paradigm via observation rather than direct measurement.

Despite the Athlete being in a state of LEA throughout the entire intervention period, they were able to complete all prescribed training sessions with no evident effect on measures of wellness or training load, which is contradictory to previous evidence (see section 2.8.5). Despite not specifically implementing objective assessments, there were also no incidences of gastrointestinal distresses or immune function disturbances, however, given no increases in catecholamine's above acceptable reference levels, this is unsurprising. Interestingly and to the authors knowledge, this is one of the first studies to characterise the effects of LEA on markers of sleep, highlighting no effect on either duration or efficiency, with these factors only being effected by fluctuations in training schedule as has been previously highlighted in athletic populations (Fullagar et al., 2016; Sargent et al., 2014). Taken collectively, all this data appears to support the idea that a threshold of <30 kcal·kg·FFM·day^{-1} may be too high to cause RED-S in male populations (Burke et al., 2018a) and could represent a value of <20kcal·kg·FFM·day^{-1} as suggested by Fagerberg (2018), although further studies in larger cohorts are warranted to conclude this definitively.

Despite the success of the intervention and no obvious symptoms of RED-S, it should be noted that post competition in the +1 WK period the Athlete underwent an excessive period of rebound hyperphagia, where EI for the entire period was in excess of 33,000 kcal·wk^{-1}. Whilst this did not result in pronounced FM overshoot, BM increased by 13.2% to near baseline levels in only 7 days. This also resulted in a pronounced effect on the Athlete's measured RMR$_{\text{ratio}}$ (>1.10), with absolute values in excess of 22% from baseline, concomitant with unfavourable triglyceride, cholesterol and LDL lipid profiles and hyperinsulinemia that represent postprandial values, despite the Athlete being assessed after a 12 hour fast.

Discussing this with the Athlete during semi structured interviews they made the following comments:

On the hyperphagic response*: '…there was probably points where I kept going back to the bag and my partner, mum or dad were like "are you eating again?" and I was just like "I need it, I want it"…I didn't quite care, to be honest, but I expected my weight to shoot up quite a bit after the fight once I'd woken up the next day. But I didn't feel too guilty [laughing]…I think there are times when I'm sort of like eating out of boredom but again, not really feeling guilty about it or, like I've ate, I don't know, anything for example, my partner or my parents are like "are you still eating?" and I'm like "yeah" but I need to my body is craving it…'*

On the cravings they felt: *'I wouldn't say that the food that I'm eating is great. I'm still sort of in that happy place, rewarding myself. I went for a meal last night so I think it is just that sort of reward feeling, but I've said to myself I'll have a little sort of break this week, a little week off training, nutritional habits will slip a little bit but will get back to it, get that weight back down…a couple of things like, a couple of times I've been thinking like hot chocolate or just like a lot of chocolate. I'd say that's the main one more than anything. Just high calorie stuff like that.'*

On how they feel about consistently eating: *'I think the main thing is, for enjoyment, like, the chocolate, little snacks, I think it is just enjoyment. No real feelings of guilt when I'm eating it or thinking about the weight to be honest… It's not reduced yet, to be honest, but I have started to think about, like, the near future, I do need to start getting back into sort of a meal plan, well not a meal plan but not eating the amount of crap I am.'*

And changes in their physique: *'I wouldn't like to go above what we originally started at. That would just make the long run even harder than the first 8 weeks so obviously l don't really want to go over…going so high so quickly hasn't bothered me or made me feel guilty but, you know, it was good to be in that sort of condition. Yeah, I've not really felt guilty that I'm not in that shape at the minute as I know I will eventually get back to it.'*

When examining this in line with the WDEB assessment it may be no coincidence that there is a manifestation of rebound hyperphagia given the large deficit induced by the intervention, which only plateaus after 7 days of excessive EI. The behaviours displayed here are also in support of the research highlighted in section 2.9, where this is inherent of recovery from a chronic interruption in energetic homeostasis.

Finally, this intervention represented a major change to the Athlete's habitual making weight practices, which also resulted in a differing perception post competition: *'My mind set's changed completely. Rather than doing that small crash 2-3 weeks before a competition and feeling like crap on the day, it is easier and much better for performance to just extend that time period and get the weight down, plus you can have the carbs. It's really made me realise carbs aren't the enemy and probably the main factor through training and performance on the day.'*

7.5. Conclusion

This case study highlights that making weight for combat sport athletes can be successfully achieved via a combination of restricted yet periodised EI according to the daily demands of training. Despite a transient period of LEA, no or minimal negative associations of RED-S consequences on both health or either tested and competitive performance parameters were apparent. Crucially this study adds to the growing evidence base that the current LEA threshold may be too high in male populations, particularly given evidence suggesting this may represent closer to <20kcal·kg·FFM·day^{-1}. Research examining the repetition of this intervention, across multiple time points, is warranted to help further our understanding of RED-S, particularly in males and potential effects of chronic LEA in combat sport athletes. However, the rebound hyperphagic response manifested by this intervention is a cause for concern. Further research is needed to understand the metabolic regulation of this condition, in line with strategies to rescue major reductions in WDEB both during and post intervention.

CHAPTER 8.

Synthesis of Findings

8.1. Synthesis of Findings

The studies presented within this thesis have provided novel data, that will significantly enhance the literature in regards to the making weight practices of international standard Taekwondo athletes, key stakeholder groups perceptions of these practices, methods to examine both body composition and exercise energetic expenditure, as well as a proposed nutritional and training intervention that can be employed without the negative associations of RED-S consequences. The following Chapter summarises the key findings of this thesis in line with the aims and objectives presented in Chapter 1. A general discussion will be presented along with limitations and practical findings, inclusive of recommendations for future research.

8.2. Achievement of Aims

The main aim of this thesis was to assess the making weight practices, influences and psychological and physiological health and performance of international standard Taekwondo athletes during BM loss for competition. To achieve this overall aim it was necessary to survey international standard Taekwondo athletes during a competitive weigh in, whilst examining differences between sexes, age divisions and OG/WT weight categories. Furthermore, it was crucial to explore the perceptions of key stakeholder groups inclusive of athletes, coaches and parents in regards to these practices, to further understand the context of how to engage identified issues in subsequent investigations. Additionally, it was a key requirement to investigate methods to measure both body composition and energy expenditure in this demographic, to provide a valid means to assess these variables in the field. If the aims of this thesis were achieved, this would then afford the possibility of creating an intervention to combat the identified issues. In Chapter 1, eight specific objectives were proposed and these will now be sequentially evaluated.

8.2.1. Assess the frequency, occurrence and magnitude of BM loss in international standard Taekwondo athletes in situ and examine potential differences between sexes, age divisions and WT/OG categories

Objective 1 was addressed in Study 1 of Chapter 3. To date, no study has surveyed the frequency, occurrence, and magnitude of international standard Taekwondo athletes directly after a competition weigh in. This demonstrated that in agreement with numerous investigations highlighted in section 2.6, that there were no differences between sexes. However, there were key differences in the approaches of making weight among athletes in the differing age divisions, which were not driven by the time spent in the sport, but rather the requirement to lose more BM, given a reduced amount of weight categories and increases in category differences among the older age groups. Frequency and occurrence were linked to the amount of events throughout a competitive season, whereas a novel finding of this study was that the range of BM loss among both Junior and Senior competitors, was much higher than has been previously characterised for OG weight categories. Furthermore, Chapter 3 also elucidated that all age divisions predominantly lose BM via chronic energy restriction and increased expenditures, whereas the older divisions additionally rely on A/RWL techniques inclusive of active and also passive dehydration, alongside more extreme methods such as fat burners, diuretics, laxatives, enemas, spitting and vomiting. In agreement with previous literature in section 2.6.8, the study also highlighted that the key influence in the decision to engage in making weight practices was coaches and team mates. However, additional influences were also identified in the form of parents in the younger age divisions and also national team selection policies.

8.2.2. Analyse the ergogenic dietary supplements utilised by these athletes, to support making weight and performance practices in tandem with knowledge of use and anti-doping histories

Objective 2 was addressed in Study 1 of Chapter 3. Coinciding with objective 1, for the first time in a large cohort of international standard Taekwondo athletes of differing age divisions, dietary ergogenic supplement use was examined highlighting a link between specific utilisation to support performance enhancement and making weight practices.

Whereas prior to competition many of the athletes utilised ergogenic dietary supplements that were purported to support weight loss and health benefits, post weigh in many indicated consumption of ‘energy’ based products. This study also identified via qualitative enquiry that the large majority of athletes had little knowledge on how to scrutinise ergogenic dietary supplements for potential inadvertent anti-doping violations, despite a proportion of the surveyed population indicting they had participated in an anti-doping test at some point in their athletic career.

8.2.3. Explore stakeholder perceptions of the influences which encourage the engagement in these practices and behaviours

Objective 3 was addressed in Study 2 of Chapter 4, which served to explore the perceptions of influential stakeholder groups identified in Chapter 3, elucidating a number of novel findings. Firstly, the athletes expressed their engagement in BM loss was not only to gain, but to also limit the advantages of opponents. None of the stakeholder groups identified any association with making weight and the importance of physique, conversely to other published research, yet this highlighted a number of issues among coaches and parents related to espoused vs. enacted values and cognitive dissonance, particularly in relation to different age divisions. Interestingly, previous or current involvement in the sport elucidated conflictions in the perceptions of making weight practices among coaches and parents, yet all agreed it was coaches who chiefly had the main influence on the athletes and they required a greater level of knowledge in order to act in this capacity. Chapter 4 also highlighted that many athletes would predominantly reduce CHO, FAT and fluid intakes, alongside reductions in meal size and frequency, in order to lose BM for a specified weight category. The relationship with CHO and fluid in the making weight phase was completely reversed in the post weigh in period, were athletes stated their importance for competitive performance. This study highlighted in even greater detail, the individual strategies of athletes post weigh in, with all expressing the desire to engage in rebound hyperphagic behaviours, with those who did describing negative gastrointestinal symptoms, not conducive with positive sleep and competitive performance. Post competition, all athletes describe a rebound hyperphagic period, which often causes internal mental confliction, particularly in relation to BM overshoot and the fear of going too far above their elected weight category. Whilst many of the athletes believed they had adequate nutritional knowledge, many described the difficulty in eating appropriately due to time restraints and economic cost. Additionally, it was highly evident the athletes had no clear understanding of how to scrutinise dietary ergogenic supplements for safe use and avoid potential inadvertent anti-doping violations. Conversely, both the coaches and parents voiced their discontent with the athletes nutritional practices believing them to be unsatisfactory. However and as identified previously, all groups expressed how a greater level of nutritional knowledge was required for all stakeholders in the sport, yet again in the coach group who have the largest influence on athletes in this area.

8.2.4. Evaluate the body composition indices of international standard Taekwondo athletes and absolute BM losses when required to make weight for OG or WT categories

Objective 4 was addressed in Study 3 of Chapter 5. To date no study has examined the difference in BM loss magnitude of international standard Taekwondo athletes required to make weight for differing WT and OG weight categories. Many of the athletes were within an acceptable 5% BM loss range up to 4 days prior to weigh in for their elected WT category, yet this increased considerably if they were required to meet their OG weight category. A large percentage of the athletes would be above 5% BM, independent of losses that could be achieved via reductions in body tissues, highlighting the requirement to engage in extreme A/RWL practices. This study also highlighted both whole BM and regional indices of BMC/D, LM and FM/% in international standard Taekwondo athletes of differing OG weight categories prior to BM loss, utilising DXA as a criterion measurement method. There were significant differences displayed between each athlete category in BMC/D, LM and FM, with younger -58 kg Fly athletes being considerably lower in most variables than older -68 kg Feather and -80 kg Welter athletes. Additionally, there were also no differences FM and LM indices between the dominant and non-dominant lower limbs in all athletes.

8.2.5. Determine the validity and accuracy of commonly utilised field based body compositional measures in comparison with criterion laboratory equipment

Objective 5 was addressed in Study 3 of Chapter 5. Coinciding with objective 3, this study compared a range of $\sum_{\mathrm{Skf}}$ FM% equations against DXA as the criterion. Two equations were identified to have an acceptable level of validity and accuracy, which can be utilised within this population for measurement of FM in the field. This will therefore aid in BM loss interventions to identify FFM with a greater level of accuracy for use in calculation of EA status. The other eight utilised equations were highlighted to have a reduced level of accuracy, where they are not recommended for use in the field and the data generated in studies employing these techniques should be interpreted with caution.

8.2.6. Design and assess the efficacy of an ecologically valid laboratory protocol, which mimics the physiological demand of Taekwondo competitive activities.

Objective 6 was addressed in Study 4 of Chapter 6. A number of studies in section 2.8.3 have highlighted the energetic cost of simulated Taekwondo bouts, but these have been conducted with laboratory based measures, which are impractical in the field. Three separate simulated Taekwondo competition pad-work (STCP-W) protocols, with varying levels of activity:recovery intensity were created and examined in tandem to data from current research investigations of actual competitive bouts. With STCP-W 1:2 demonstrating the highest level of ecological validity, this protocol could now be used in future investigations examining the parameters of competitive bouts within laboratory or field based settings and as a sport specific conditioning intervention independent of full contact activities.

8.2.7. Establish the validity and accuracy of field based and criterion measurements of AEE during use in an ecologically valid laboratory protocol

Objective 7 was addressed in Study 4 of Chapter 6. Whilst there is a body of research examining the AEE of Taekwondo activities in the laboratory, field based measures have been conducted but with non-validated portable actigraphy units, which may provide significant under or overestimations. In this study the Actiheart combined accelerometer and HR portable actigraphy unit was validated for the acceptable measurement of AEE, against indirect calorimetry as the criterion standard within all the STCP-W protocols designed in objective 6. This now makes assessment of the energetic cost of both training and competition in ecological settings more feasible and was essential along with the findings of Chapter 5 for the calculation of EA and WDEB status during the nutritional and training intervention in Study 5 of Chapter 7.

8.2.8. Examine the effect of a periodised nutritional and training intervention on symptoms of RED-S consequences while making weight for competition

Objective 8 was addressed in Study 5 of Chapter 7. Through the findings of Chapters 5 and 6, it was possible to assess the EA status of Taekwondo training and competition activities, which have not been characterised previously. Utilising the data from all subsequent Chapters, an alternate nutritional and training intervention was implemented for an international standard Taekwondo athlete losing >13% BM over a gradual period of 8 weeks, without the need to engage in extreme A/RWL techniques. Additionally the examination of RED-S consequences on both health and performance, highlighted minimal negative associations despite LEA status throughout the intervention. The findings of this study are novel and demonstrate that international Taekwondo athletes can make specified weight categories, without disturbances to psychological and physiological health and performance as described in Chapters 3 and 4.

In summary it can be concluded that the aim and objectives set out in Chapter 1 of this thesis have been achieved and consequently the findings of the subsequent studies have significantly added to the literature, in regards to the psychological and physiological effects of making weight in international standard Taekwondo athletes.

8.3. General Discussion

Chapter 2 highlighted there is general paucity of research examining the making weight practices of international Taekwondo athletes during BM loss. Those studies which have been conducted, are largely descriptive and despite being a new area, no investigations to date have examined the potential of LEA status or RED-S consequences on the health and performance of this athlete demographic. Additionally, no current research has investigated if an alternate approach to making weight could be employed for reductions in RED-S syndromes. The five studies undertaken in this thesis provide novel findings, which serve to enhance the making weight practices of international standard Taekwondo athletes, in relation to behaviours, education, assessment of WDEB/EA status and structured dietary and training guidance, all of which can enhance the health and performance of this demographic during BM loss for competition.

By examining the reductions in weight categories and increases in category differences throughout the age groups in Chapter 3, it should come as no surprise that Senior division athletes have a requirement to lose greater amounts of BM for competition. This in turn results in the need to engage in extreme making weight behaviours, inclusive of methods which may negatively affect health and can cause potential injury or death. The descriptions of these effects, by both athletes and external stakeholder groups, highlight that there is no desire to engage in these practices, yet they are deemed necessary to improve performance advantages. Stakeholder perceptions examined in Chapter 4, highlighted that whilst many of the groups felt they were educated in making weight and nutrition, there was a genuine desire to be further upskilled in these areas, independent of sporting or non-sporting involvement. There was also a clear message that national and global federation governing bodies should be driving this process, with an objective view of protecting athlete health above all else, by integrating additional weight categories. Ironically it appears that this is a vicious cycle, whereby the weight categorisation of the sport to protect the athletes from contests between competitors of unfair proportion, is having a detrimental effect on athlete health in preparation for competition. Ultimately this can only be mitigated by changes in rules and regulations of weight categorisation and/or to better educate those within the sport to safely manage making weight practices for specified categories.

Chapter 5 highlighted that many of the athletes within the sport were engaging in A/RWL, yet still had body compositional tissues which could be modulated to further reduce BM independent of these practices. However, this information can only be accurately assessed by criterion methods, which are often not available outside of research settings. On that basis this thesis has provided a means to assess body composition with greater accuracy in the field, with ecologically and economically valid tools. By arming practitioners with the ability to measure the potential for BM losses, this in turn with an improved education platform, should translate into the ability to justify making weight for specified categories, based on a more scientific rationale and within safe and ethical boundaries of practice. As defined in Chapter 6, the ability to measure body composition alongside exercise energetic expenditure, in various field based sport specific activities, can again afford the possibility to measure EA status. This in tandem with a host of other subjective and objective measurements, can provide meaningful information about athlete health during the engagement in making weight practices. Finally, the nutritional and training intervention prescribed in Chapter 7, highlights how making weight in international standard Taekwondo athletes can be achieved both safely and effectively. However, it must be considered that the methods provided in Chapters 5 and 6, alongside those which measured a more global view of EB, is what makes this intervention so successful. To conclude and coin an excerpt of Sun Tzu from the Art of War:

'The general who wins in battle understands his battle ground and makes many calculations in his temple ere the battle is fought. The general who loses the battle makes but a few calculations beforehand. Thus do many calculations lead to victory and few calculations to defeat. It is by attention to this point that I can foresee who is likely to succeed and who is likely to fail in battle.'

A schematic representation of the main findings of this thesis are presented in Figure 8.1.

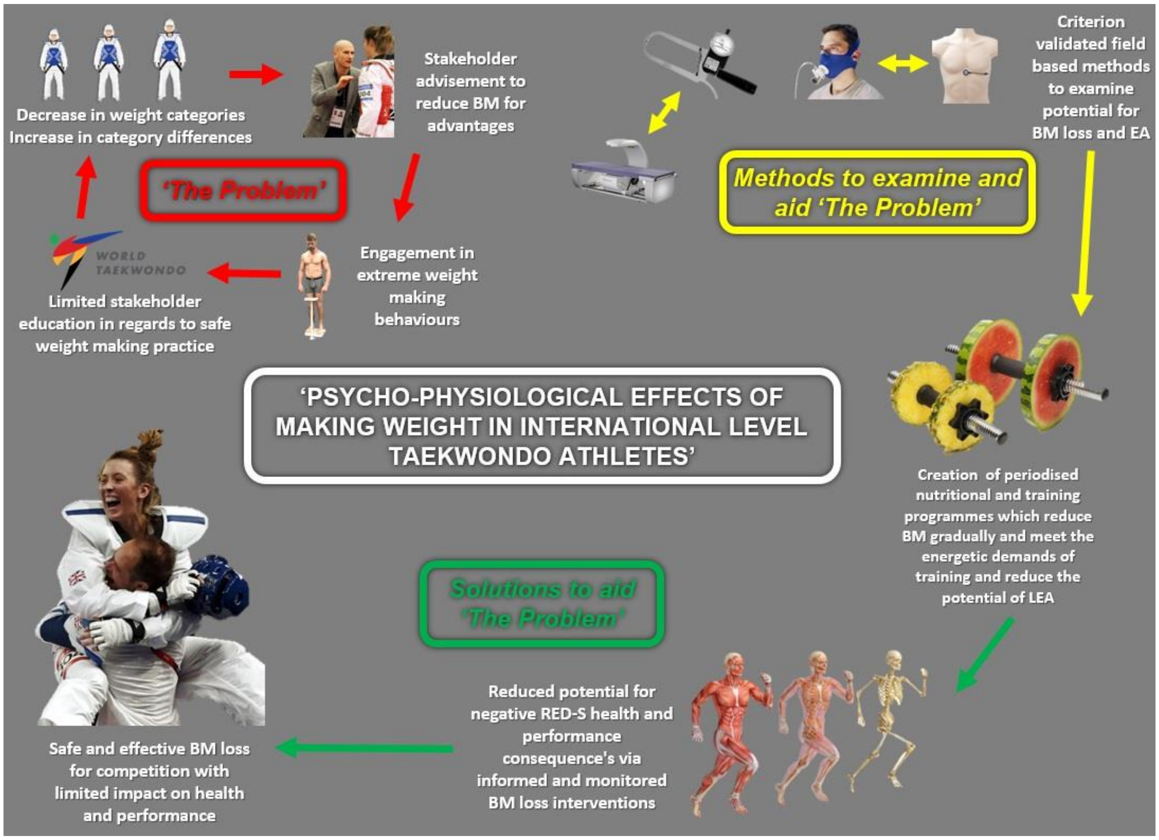


Figure 8.1. *Schematic representation of the main findings of this thesis.*

The necessity to make weight via the prescribed weight categories (Chapter 3) results in Taekwondo athletes being advised by support group networks (Chapter 4) to engage in negative BM loss practices, which may cause LEA and RED-S (Chapter 3 & 4). Through a better understanding of body composition (Chapter 5) and exercise energy expenditure measurement (Chapter 6) in this demographic, an alternate nutritional and training strategy was implemented and despite LEA, resulted in minimal negative consequences associated with RED-S syndromes (Chapter 7).

8.4. Limitations

The present thesis has significantly advanced the knowledge, in regards to the psychological and physiological effects of making weight, on the health and performance of international standard Taekwondo athletes. The research undertaken, has resulted in 5 conference communications, two invited research talks at University institutions, an applied BASES article and also a book chapter. These studies have also recruited participants who could be classified as ‘elite’, inclusive of national, international, continental, world and Olympic medallists who are at the highest level in the sport. However, despite the strength and novelty of this thesis, it is not without its limitations. A number of these limitations are related in the desire to maintain the highest level of ecological validity, limited participant demographics, and/or the inability to take measurements *in situ.* The main limitations of the thesis will now be outlined.

8.4.1. Study 1 – Body Mass Loss and Ergogenic Dietary Supplement Practices in International Standard Taekwondo Athletes: Effects of Sex and Age Division

Due to the survey being conducted prior to the new WT 5% re-weigh in ruling, it is difficult to ascertain if this has yet had an impact on the BM loss behaviours of this athlete demographic and may have reduced the frequency, occurrence and magnitudes displayed in this study. A limited sample size in comparison to previous investigations, with uneven groups in each age division and between sexes, also does not allow a balanced and complete representative view of the entire targeted population. Finally, given the close proximity of the survey post weigh and driven by the desire to rehydrate and refuel above all other priorities, this may have resulted in the reduced qualitative responses received and in potentially convoluted replies throughout.

8.4.2. Study 2 – Stakeholder Perceptions of Making Weight and Nutritional Practices in International Standard Taekwondo Athletes.

The reduced sample size among the stakeholder groups in this study, hinders a deeper analysis of the currently presented perceptions or affording additional opportunities to elucidate further insights. There was no survey of athletes from the younger age divisions, which would serve to confirm some of the asserted views of Coach and Parent groups and this should certainly be addressed in future research. Despite the familiarity of the interviewer being perceived as a positive, this could also be construed as a negative given they may contaminate lines of enquiry with their own preconceived notions and biases. Finally as all interviews were conducted via telephone and not face to face, this may have resulted in loss of contextual and nonverbal data, whilst compromising the rapport, probing, and interpretation of responses.

8.4.3. Study 3 – Magnitudes of Body Mass Loss Between Olympic and World Weight Categories and Measurement of Body Composition Indices in International Standard Taekwondo Athletes

This study has only been conducted in a Senior male population, with a limited number of participants and at one distinct time point. Additionally despite the best efforts to standardise measurements during DXA assessment and utilising a best practice protocol, an examination of TBW would have provided a clearer understanding of the hydration status of each athlete prior to scanning, given they may have been hypohydrated due to the close proximity of the competition weigh ins.

8.4.4. Study 4 - Comparisons of Perceptual, Physiological and Energy Expenditure Measurement During Simulated Taekwondo Competition Bouts: Influence of Differing Activity:Recovery Ratios.

There are a number of limitations associated with this study. Firstly whilst all the data may prove useful in the context of international standard Taekwondo athletes, this has only been conducted in males, with a small sample size, further limited by the number in each weight category. Whilst indirect calorimetry may be regarded as a field based criterion measurement for the assessment of AEE contributions, the Polar RS400 CHRM for measurement of HR is not and the study would have benefited greatly from utilising portable ECG for this variable. However, given the placement position of the Actiheart electrodes this was not feasible. A key limitation was the absence of total energy systems AEE data, which ignores the contributions of anaerobic metabolism and also the calculation of EEE via AEE with the removal of TEE variables. However, given that the

Actiheart branch chain equation calculation is based on regressions from solely the aerobic component of AEE, it was decided to focus on this independently. This study has utilised calculations of AEE rather than EEE, given that measures were not undertaken to estimate the other components of TEE, however, as the ‘gross’ AEE values of both the Actiheart and indirect calorimetry would result in the same reductions of TEE, this would not confound the least squares comparisons employed during the statistical analysis. Finally, whilst conducted in laboratory conditions and with strict controls, the ecological validity of the study can also be questioned. Despite wearing similar typical training attire, this was in the absence of the protective equipment worn in competitive bouts. The size of the competitive area was reduced given the footfall of the indirect calorimetry equipment and the kicking combinations were limited to multiples of a singular technique. Whilst these restrictions were necessary to control for comparisons of both conditions and measures of HR and AEE, these protocols should now be conducted in more ecologically valid setting to test the robustness of the study design.

8.4.5. Study 5 - Making Weight Safely: Manipulation of Energy Availability and Within Daily Energy Balance Without Symptoms of RED-S in an International Standard Taekwondo Athlete

Being a case study, an obvious limitation is due to the reduced sample size. Additionally, despite the EI being well controlled via the provision of all meals throughout the study, this can be regarded to have low ecological validity, given this would not ordinarily occur in practice. The study would have benefited greatly from the measurement of core temperature for potential associations of AT, however, the participant would not allow rectal measurement. Finally, the absence in examination of, T_3, T_4, leptin and ghrelin biomarkers, due to being unable to analyse the assays for these measures, does not allow a more global view of the neuroendocrine metabolic interactions of both LEA and rebound hyperphagia.

8.5. Practical Implications

From the findings of the five studies within this thesis, there are number of important practical implications that may be considered by international standard Taekwondo athletes and their gatekeepers, inclusive of coaches, trainers and national/global federation governing bodies as follows:

1. Due to the reduction in weight categories throughout the age divisions, targeted making weight and nutritional education should be provided for the Cadet and Junior athlete groups. This in turn should lead to improved behaviours of BM loss as the athletes progress through each age cycle. However, ultimately the results of this thesis have added to the growing literature, highlighting a need for more weight categories in the Senior division, particularly in Olympic and respective qualifying events.

2. The results of numerous Chapters within this thesis, have highlighted the nutritional knowledge of all stakeholders, principally inclusive of both athletes and coaches is poor and current policy and education is inadequate. Targeted educational packages should be designed, considering the recommendations of stakeholders in Chapter 4, which cover a range of sport nutrition topics inclusive of anti-doping information and the use of dietary ergogenic supplements. First and foremost, this education should be targeted at coaches and could form part of national, continental and global licensing platforms, given this stakeholder group is considered the gatekeeper of athlete advisement in all matters relating to performance.

3. The assessment of body composition in Chapter 5 now provides novel data and also valid and accurate methods of assessment, which can be employed in the field. Whilst $\sum_{\text{Skf}}$ are often prescribed as the most appropriate for use in athletic populations, this gives a limited view of compositional tissues, whereas the validated equations highlighted in this thesis, may give practitioners a more contextual view of how BM loss can be achieved safely without negative impacts on both health and performance.

4. The examination of AEE in Chapter 6 also provides a means whereby this can now be assessed with a greater level of accuracy in the field. This allows for collection of data in ecologically valid settings, inclusive of full contact actions in competition, which are still as yet uncharacterised in the literature.

5. The STCP-W protocol designed in Chapter 6 now also provides a novel means of assessing the physiological responses of competition within a laboratory setting, which was previously considered impractical. The ecological validity of the activity:recovery ratios in STCP-W 1:2 protocol, also allows this to be considered for non-contact based training interventions, particularly during taper periods leading into competition where injury reduction is essential.

6. The novel assessment of WDEB highlighted in Chapter 7, now allows practitioners to examine fluctuations in energetic status throughout a global 24 hour period. The accumulative assessment of imbalances in energetic homeostasis, takes into consideration a more holistic view of both EI and training based periodization, for the harmonisation of gradual BM losses with reduced potential for RED-S consequences.

7. The periodised dietary and training intervention proposed in Chapter 7 could now also be utilised by athletes when making weight for specified categories, reducing the negative psychological and physiological effects highlighted in Chapters 2 and by the athlete participants in Chapters 3 and 4.

8. It appears that despite the potential for LEA status among this demographic during making weight, Chapters 5 and 7 have elucidated the osteogenic stimulus of Taekwondo training activities may offset any negative effects of RED-S on bone health.

8.6. Recommendations for Future Research

Based upon the findings of this thesis, future research is now required to further our understanding of the psychological and physiological effects of making weight in international Taekwondo athletes. The following recommendations are considered for potential research studies:

1. The repetition of Chapter 3, considering the impact of the new 5% re-weigh in ruling: *An additional study could classify if the new ruling has had an impact on reducing the high frequency and magnitudes of BM loss, described within Chapters 3 and 4 of this thesis.*

2. The design and validation of an educational platform for differing stakeholder groups: *This study could create a number of educational platforms for differing stakeholder groups via both face to face and online platforms and then validate them for use within the sport for the improvement of making weight behaviours.*

3. The repetition of Chapter 3 and 4, considering the impact of an education platform for stakeholder groups: *This study could additionally examine the efficacy of an education platform on the perceptions of a wider stakeholder group, as described in Chapter 4. Additionally, this could also serve to explore the means of making targeted education more effective.*

4. Examination of the validated $\sum_{\text{Skf}}$ equations proposed in Chapter 5, across multiple time points in a training camp: *An assessment of the efficacy of the proposed body composition methods from Chapter 5 across multiple phases in a season, are vital in understanding if the validity of this tool also has accuracy and reliability. This should also be considered for use in females and younger athlete age groups.*

5. The repetition of Chapter 6, utilising a more ecologically valid setting and protocol inclusive of updated equipment: *Whilst the findings of Chapter 6 were useful in highlighting the potential for the Actiheart unit in examining EEE, this would be further improved by utilising a protocol with a greater amount of techniques and in a larger footfall area. Additionally, the Actiheart is now available with a Polar* WearLink®+ *chest strap, which reduces the potential for error in measurement from movement of the unit.*

6. The repetition of Chapter 7 in a large cohort: *The findings of Chapter 7 clearly demonstrated the efficacy of the employed nutritional and training strategy, therefore justifying the repetition of this intervention in a larger cohort and inclusive of female athletes.*

7. An extended examination of rebound hyperphagia and across repeated training camps: *The findings of Chapter 7 demonstrated a number of positives in relation to making weight safely for competition and avoiding the negative consequences of RED-S. However, the rebound hyperphagic behaviours displayed post intervention and resulting in BM/FM overshoot require a greater understanding. A study of this paradigm across an extended post competitive period and sequential training camps, utilising a multi methodological approach of psychological and physiological examination is certainly warranted.*

8. Recruit a cohort of retired Taekwondo athletes: *The findings of Chapter 4, elucidated that rebound hyperphagic effects of weight cycling may elicit major BM and FM overshoot in later life, post retirement. A dual quantitative/qualitative assessment of retired international standard Taekwondo athletes, may be an appropriate starting point to examine the long term effects of repetitive making weight practices.*

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APPENDICES

APPENDIX 1

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

This questionnaire is about pre-competition short/long term weight loss and supplement use.
Please answer the questions with as much **attention** and **seriousness** as possible.
Liverpool John Moore's University thanks you for your participation
I have read the information sheet provided and I am happy to participate. I understand that by completing and returning this questionnaire I am consenting to be part of this research study and for my data to be used as described in the information sheet provided. You can leave questions unanswered throughout this questionnaire and withdraw at any time.

GENERAL INFORMATION

1. Age: _____years.
2. At what age did you begin **practicing** Taekwondo? ________years.
3. At what age did you begin **competing** in Taekwondo? ________years.
4. How much did you weigh in today? _____kg.
5. How tall are you? _____cm.
6. Please describe your achievements and participation in Taekwondo competitions to date:

National level competition (*i.e. Scorpion Open, NTC Open, British National Championships etc.*)
(   ) participated without winning a medal **(   ) won a medal** **(   ) never participated**

International level competition (*i.e. Dutch Masters, NWTU Masters, Belgium Open etc.*)
(   ) participated without winning a medal **(   ) won a medal** **(   ) never participated**

G-Class level competition (*i.e. G1, G2, G4, G8, G12, G20 etc.*)
(   ) participated without winning a medal **(   ) won a medal** **(   ) never participated**

7. How many times did you compete in the last year (including 1-2-1)? _____
8. In how many competitions did you win a medal in the last year (including 1-2-1)? _____

WEIGHT HISTORY AND DIET PATTERNS

9. In which weight class do you compete? - / + _____kg. In which **OLYMPIC** weight class do you compete? - / + _____kg.
10. Did you change weight class in the last 2 years?
(   ) Yes. In which weight class/es did you compete? __________
(   ) No. I competed in the same weight class in the last 2 years.

11. How much did you weigh in the last Taekwondo off season (i.e. December/Christmas)? _____kg.
12. Have you ever lost weight in order to compete?
(   ) Yes. Please continue onto question 13.
(   ) No. Please go to question 19.

13. What is the MOST WEIGHT that you have ever lost to compete in your career? _____kg.
14. How many times did you lose weight to compete this year? _____times
15. How much weight do you usually lose before competitions? _____kg.
16. In how many days do you usually lose weight before competitions? _____days.
17. At what age did you begin losing weight for competitions? _____years old.
18. How much weight do you usually regain in the 7 days following a competition? _____kg/wk.

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

19. Using the scale below, please rate the amount of influence that each individual listed below has had on your weight loss practices. (*i.e. who encouraged you and/or taught you to lose weight for competition?*)

1	2	3	4	5
not influential	minimally influential	unsure	quite influential	very influential

( ) training colleague
( ) another Taekwondo competitor
( ) physician/doctor
( ) physiotherapist
( ) S&C coach/PT
( ) Coach/Trainer
( ) Nutritionist/dietician
( ) Parents
( ) Internet. Please specify source_______________
( ) Social Media. Please specify source_____________
( ) YouTube
( ) Other. Explain________________

20. The following tick boxes present several methods of weight loss. Please state <u>**HOW OFTEN**</u> did you use each one of the following methods to lose weight <u>**before competitions**</u>? (Please check all items).

Gradual dieting (losing weight in 2 weeks or more)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

How long before a competition would you start? How much did you lose per week? Would you do it again? How did this make you feel? i.e. symptoms of fatigue, loss of strength, low mood, light headed / dizzy, sore throat, increased appetite etc.

Skipping 1 or 2 meals (in a day)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Did you restrict certain types of food? How long would you do this for?

Fasting (not eating all day)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

How long would you do this for? Would you do it again?

Restricting fluids (deliberately not drinking)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Did you restrict certain types of fluid? How long would you do this for?

Increasing exercise (more than usual)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

What type of exercise did you do? How long would you do this for?

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

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Saunas/steam room (deliberately trying to sweat for weight loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

What did you do? How long did you stay in? Did you exercise? How much weight did you lose? Did you wear clothing?

Sweat suits (deliberately trying to sweat for weight loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

When did you wear it? How long for? How much weight did you lose?

Hot/Salt bath (deliberately trying to sweat for weight loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

What did you do? What type and how much salt did you use? How long did you stay in? How much weight did you lose?

Diet pills (carbohydrate or fat blockers)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

What type/brand and are they prescribed or over the counter? How much did you take? How often did you take them and for how long? How much weight did you lose? Would you use them again? How did these make you feel?

Fat burners (to increase fat loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

As above

Diuretics (tablets that cause you to lose fluids i.e. increased toilet use)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

As above

Laxatives (tablets that cause bowel movements i.e. increased toilet use)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

As above

Enema and/or colonic irrigation (a procedure to remove gut waste and fluids)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Where was this done? How much weight did you lose? Would you do it again? How did this make you feel?

Spitting (deliberately trying to spit out saliva for weight loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

As above

Vomiting (deliberately trying to vomit for weight loss)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

As above

Water loading (drinking excessive amounts of water whilst reducing sodium intake)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

How many litres per day did you drink? How many times did you do this? How much weight did you lose? Would you do it again? How did this make you feel?

What is your normal routine after you have made weight?

Do you take supplements? (For any answer other than 'never used' please complete the relevant supplements tick boxes which are in alphabetical order).

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

BCAA's (Branched Chain Amino Acids)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

What type/brand? Manufacturer? Do you know if this brand is tested for banned substances i.e. Informed Sport? What were the dosages/timings of your intake? How long did you take them for? Would you use them again?

β-Alanine (Beta- alanine)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Bovine Colostrum
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Caffeine (including coffee)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Carnitine
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Carnosine
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Casein Protein
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Chromium
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Cissus
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

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CLA (Conjugated Linoleic Acid)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Coenzyme Q10

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Creatine (all forms)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Desiccated Liver

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Digestive Enzymes

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

EAA (Essential Amino Acids)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Electrolytes (including drinks i.e. Lucozade Sport/Powerade and/or tablets i.e. SiS Go Hydro)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Energy Gels
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Energy Bars
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Energy Drinks (including both still and carbonated brands)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Ephedra
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Fish Oils (including Cod Liver, Omega 3/6/9, Krill Oil etc.)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Ginseng
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Glutamine
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

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Glucosamine

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

Glycerol

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

Green Tea (including extract)

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

Guarana

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

HMB (Beta-hydroxyl beta-methyl butyrate)

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

Manuka Honey

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

MCT's (Medium Chain Triglycerides)

(   ) always (   ) sometimes (   ) almost never (   ) never used (   ) I don't use anymore

Meal Replacement Supplements (including bars and powders)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

MSM (Methyl Suffonyl Methane)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Phosphate Salts
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Post work out products (taken after any training sessions)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Pre work out products (taken before any training sessions)
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Pro Hormones
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Quercetin
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Sodium Bicarbonate
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Sodium Citrate
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Soy Protein
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Tart Cherry Juice
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Testosterone Boosters
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Tribulus Terrestris
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Vegan Protein
( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

LJMU TAEKWONDO WEIGHT LOSS QUESTIONNAIRE

adapted from Artioli et al. 2010

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Whey Protein (all varieties including isolate, concentrate, hydrolysate etc.)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

ZMA (Zinc Monomethionine Aspartate, Magnesium Aspartate and Vitamin B6)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Vitamins (including both multi and/or individual vitamins)

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Others. Please state____

( ) always ( ) sometimes ( ) almost never ( ) never used ( ) I don't use anymore

Have you ever been required to take a drugs test? (If no you have completed the questionnaire).

( ) YES ( ) NO

Was/were these in or out of competition drugs test/s? (Please tick all necessary answers).

( ) OUT OF COMPETITION ( ) IN COMPETITION

Which method/s were used on these drugs test/s? (Please tick all necessary answers).

( ) URINE ( ) BLOOD

How many drugs tests have you undertaken in your career? __________

THANK YOU FOR YOUR PARTICIPATION

APPENDIX 2

Interview Questions – Athletes

Using a semi-structured approach, the main questions (or similar) will be asked, with the points beneath each one potential areas to navigate during the interview.

1. Do you currently have to make-weight?
    i. How much do you lose and why?
    ii. How often and for how long?
    iii. What method(s) do you use?
    iv. How difficult do you find it mentally and physically on your body?
    v. Is your physique important to you?

2. What is your normal routine after making-weight?
    i. After weigh in?
    ii. On competition day?
    iii. Between competition periods?
    iv. In the ‘off season’?

3. Who or what would you say has the biggest influence on your decision to make-weight?
    i. Coaches/professional staff?
    ii. Team mates/other competitors?
    iii. Selection policies?
    iv. Friends and family?

4. Describe to me your current dietary habits.
    i. Breakfast through to bed
    ii. Why do you eat this food at this time?

5. Who or what influences the foods that you eat?
    i. Peers/Coaches/Friend/Family
    ii. Cost / time
    iii. Competitive weight required

6. What do you think about your current nutritional practices?
    i. Are you happy with type / quality of your choices?
    ii. Do you think a change is needed – if so what?

7. Would you say you have good nutritional knowledge?
    1. To make / lose weight
    2. For health

Interview Questions – Coaches

Using a semi-structured approach, the main questions (or similar) will be asked, with the points beneath each one potential areas to navigate during the interview.

1. Are you aware of / work with Taekwondo athletes who have to make weight?
    - i. How much do they lose?
    - ii. How often and for how long?
    - iii. What method(s) are you aware of?
    - iv. What impact physically/mentally have you witnessed it have on these athletes?
    - v. Is the athlete’s physique important to you as their coach?

2. What is your opinion of the weight making methods employed by many Taekwondo athletes?
    - i. A necessity of the sport / a necessary evil?
    - ii. A fundamental part of the sport/something you have engaged in yourself?
    - iii. They are reckless methods which are unnecessary if approached properly?

3. Who or what would you say has the biggest influence on the athletes decision to make-weight?
    - iii. Coaches/professional staff?
    - iv. Their team mates/other competitors?
    - v. Selection policies?
    - vi. Their friends and family?

4. What do you think about the nutritional knowledge/practices of the athletes you work with?
    - i. Are you happy with their choices?
    - ii. Do you think these athletes need more guidance?
    - iii. Do you think a change is needed – what?

Interview Questions – Parents

Using a semi-structured approach, the main questions (or similar) will be asked, with the points beneath each one potential areas to navigate during the interview.

5. Are you aware of any Taekwondo athletes who have to make weight?
    i. How much do they lose?
    ii. How often and for how long?
    iii. What method(s) are you aware of?
    iv. What impact physically/mentally have you witnessed it have on these athletes?
    v. Is the athlete's physique important to you as their parent?

6. What is your opinion of the weight making methods employed by many Taekwondo athletes?
    i. A necessity of the sport / a necessary evil?
    ii. A fundamental part of the sport/something you have engaged in yourself?
    iii. They are reckless methods which are unnecessary if approached properly?

7. Who or what would you say has the biggest influence on the athletes decision to make-weight?
    vii. Coaches/professional staff?
    viii. Their team mates/other competitors?
    ix. Selection policies?
    x. Their friends and family?

8. What do you think about the nutritional knowledge/practices of the athletes in Taekwondo?
    i. Are you happy with their choices?
    ii. Do you think these athletes need more guidance?
    iii. Do you think a change is needed – what?

APPENDIX 3.1

GROUP	SEX	PARTICIPANT	MOTIVATION FOR BM LOSS	BM LOSS MAGNITUDES	ANNUAL BM LOSS ATTEMPTS	TIMECOURSE OF BM LOSS
ATHLETE	**FEMALE**	**Athlete 1**	*- I used to enjoy fighting at that weight because I did quite well in that category. I had a height advantage so that was a good reason as well.*	*- I'd have to lose about 4 to 5 kilos every time.*	*- I'd say over the twelve months there was probably a competition once a month, maybe more sometimes, so on average 12.*	*- I'd probably start preparing about 3 weeks before.* *- About 3 to 4 days was like the hard core sort of diet.*
		Athlete 2	*- Just to get down to that lower category, to try and give myself the best opportunity to compete at a higher level as I'm a shorter player, in each weight category you've got taller players, so the lower the category the less likely they are to be as tall.*	*- It's usually around 3-4 kilos each time I've made weight.*	*- It's usually for around 10 competitions in a year I make weight.*	*- About 2-3 weeks beforehand I start losing the weight.*
	MALE	**Athlete 3**	*- All my Taekwondo career I've had to make weight.* *- I guess like all other athletes, you've got to make it otherwise you're fighting tall and heavy opponents.* *- Just to be competitive…The height and then I was much faster than a lot of the fighters in that category.*	*- I used to lose between 3 and 5, sometimes 6 kg, usually about 4. So it was within that region of 3-6 kg.*	*- At a guess between 10 and 12. I compete once a month, sometimes every now and again twice a month, if I missed a month. So I'd say between 10 and 12.*	*- I used to try and do it over 2 to 3 weeks.*
		Athlete 4	*- Well I had to get to that weight on the basis of it being an Olympic category for selection and then obviously because I was more competitive. I was a lot taller and stronger than the other guys in the category.*	*- I'd come down from 63/64 kg so I'd probably lose around 5 or 6 kilos.*	*- Last year, as an average I did it about 11 times but sometimes it would be like one competition and then three weeks later I'd be back on it again and a couple of competitions would be two weeks apart.*	*- I'd start about 3-4 weeks out before the competition, so my target was to be 61.8 kg 14 days out before the competition.*

ATHLETE	**MALE**	**Athlete 5**	*- Just the old kind of adage of if two people are equally skilled the bigger guy will win.*	*- I'd be from anywhere between 73 – 75 kg down to 68 kg so maybe 6-7 kg.*	*- About 12 times throughout just over a year I'd say but one of those times was kind of within five days of each other.*	*- 3 to 4 weeks. I think it was kind of arbitrary, it just seemed like a long enough time to get on top of it. I'd start 28 days before I'd weigh in.*
COACH (previous competitor)	**FEMALE**	**Coach 1**	*- I mean I think while they're still growing, I don't agree with making them lose weight.* *- I don't agree with doing it with cadets and juniors. Seniors are old enough to make their own mind up but I don't think they should do it to extremes.* *- I think it's part and parcel in a in a sport that's come from making and playing at different weights, people are going to be on it all the time.*	*- I don't allow mine to lose weight, other than maintaining up to about a kilo over and a lot of mine at the minute are junior and cadets and if they go above that then I make them move up.* *- I mean, I don't think that seniors should be coming down more than a couple of kilos.*	*- Well they're fighting every month these days so at least 12 times a year.*	*- If they're cadets or juniors, they'll lose that last kilo and a half in maybe a week or two before the event.*
	MALE	**Coach 2**	*- Well, most athletes have to make weight at some stage.* *- Making weight in all combative sports is fundamental, whether you're talking Boxing, Judo, MMA, Taekwondo, they'll always do that because there is an advantage in making weight* *- If I'm being honest, I think, the majority of the coaches and athletes have no clue about making weight.*	*- My senior athletes, on average will be walking around about 6 kilos over their weight.* *- I think with the cadets and even juniors, then you've got to look at the weight categories. If you're expecting them to lose 3 kilos you've got to look at the percentage that they're losing or it isn't safe.*	*- If you've got an athlete who is doing G1 and G2 competitions regularly, I would say they would be losing weight probably every 4-6 weeks in a year, you know.*	*- They'll go on a period of within 4 weeks or 5 weeks of a competition and that's the senior and junior athletes.* *- Cadets it's got to be more short term…maybe a couple of weeks.*

COACH (previous competitor)	**MALE**	**Coach 3**	*- I think it's a bad thing in a sense of we've created a type of athlete at certain weights therefore people feel they are required to lose a massive amount of weight.* *- There's this ideal of you must be tall and skinny otherwise the national team won't pick you, so therefore people are happy to be cutting down to lower categories which is very unhealthy for the athlete, it ruins bodies, it ruins an athlete.*	*- Cadets, I'd say 1 kg maximum.* *- Juniors you're probably looking at 2 kg.* *- Seniors are the biggest losers, generally between 4 and 5 kg.*	*- Well they compete a lot now. Not like the old days so yeah, I'd say maybe 8-10 times a year.*	*- Because cadets generally lose 0.8 or 1 kg as a maximum and they'll do it within a 2 week period and they're always fine.* *- The juniors, seniors, they can do it around 3 to 4 weeks, which is a good time to start but then sometimes with a few guys they'll do it within 2 weeks and try and lose 5 kg plus, you know, the unhealthy way.*
COACH (non competitor)		**Coach 4**	*- Honestly I think if you are going to be competitive at the elite level, if you went into a competition at the weight group you walked around at you'd struggle.* *- If you want to be successful its fundamental. How many senior athletes that win category's at major championships, walk around at normal weight? I'd say zero.* *- I think that depends on what your core values are, you know what I mean, as a coach. There's probably a high percentage of people doing it wrong, especially at domestic level because there's no education for them.*	*- For a cadet, it's roughly a kilo, kilo and a half, you know, that's what I tend to advise.* *- A junior it is more like 2-3 kg at worst case.* *- Seniors, tend to lose a lot more it depends on what weight they are.*	*- We compete at least once a month so 12-14 times a year.*	*- You look at about 3-4 weeks, I'd say two weeks absolutely minimum because if you're trying to drag off a kilo and a half off a cadet or a junior in the last week, it is going to be a problem.*

COACH (non competitor	**MALE**	**Coach 5**	*- The ones who are elite cadets and juniors and seniors, they're the ones where you can receive a real beating from their opponents if you're not in the right categories.* *- I think it's a necessity in order to win, however, I think the cost of this might outweigh the benefits for some people.*	*- So in the cadets it's about 1-1.5 kilos. I won't let them lose more than that. If they need to lose more than that I just move them up because they're growing.* *- With the juniors probably 2 kilos maximum, 2.5 if we absolutely have too. Seniors 3-4 kilos plus. Given the Olympic categories sometimes you've just got to push the boundaries.*	*- So the elite divisions, they compete once a month on average, let's say, so a G1 event every month, throughout the year.*	*- Senior guys tend to take around a 3-4 weeks. As juniors and cadets lose less they do it in less time maybe a couple of weeks.*
PARENT (Taekwondo)	**MALE**	**Parent 1**	*- It was a constant struggle to get my daughters weight right to be honest.* *- I think it is a part of the sport and it is probably a part of all weight controlled sports as being able to be at your peak and at the top of your weight.* *- It's part of the battle and I can't see how you can do away with that, you know, there's no other way of doing it, I don't think.* *- Height and reach are really important.*	*- 1-2 kilos at the most for cadets and juniors I should imagine.* *- Well ideally we'd be looking at just a couple of kilos but I'm sure that quite often it would be a bit more than that. You're talking 4-5 kilos in some cases and then, they're doing it on a regular basis as well, the senior athletes.*	*- So there's an open every month, they're doing it probably more regularly and going up and down a bit too often.*	*- It always tends to be over a 3-4 week period for the older guys, the seniors.* *- Cadets and juniors take less time, I wouldn't advise any more than 2 weeks.*

PARENT (Taekwondo)	**MALE**	**Parent 2**	*- It's an absolute necessity to lose the weight and be competitive in a category.* *- I realise that we're very bad at losing weight in Taekwondo. We're just not educated. But I don't necessarily think that's a fault with the players. I think it's a fault with the coaches. The coaches just aren't educated enough.*	*- With my athletes they are never three kilos outside of their weight.* *- I have worked with athletes in the past where they would be as much as 6-8 kilos out of weight, but they just haven't managed their weight very well, to be honest.*	*- When we're training seriously we're normally competing every couple of months, so as much as 10 times a year I would say.*	*- 3-5 weeks prior to the competition they'd start cutting weight.*
PARENT (non Taekwondo)		**Parent 3**	*- Generally I would say it's a very common theme for athletes to be cutting weight.* *- It has become more common in cadets and juniors and I think it is being driven, if I'm honest, what drives it in my opinion is the national teams stance about needing taller players.* *- I think it's become a necessary evil but as in every walk of life, every type of sport, there'll always be somebody who'll take it just that one or two steps further, you know.*	*- My daughter is junior and is losing up to 3 kg to make her target weight.* *- My son also competes in senior and he has to lose around about 4 kilo, maybe even 5 kilo.*	*- Well they're both competing every month so it would be at least 12 times a year I'd say.*	*- Certainly with my daughter she will lose it in at least 3 weeks.* *- For my son, now he's older we leave it more to himself and he'll probably take that last two weeks to cut down if he's pushing it.*

PARENT (non Taekwondo)	**FEMALE**	**Parent 4**	*- She didn't really struggle until the end of juniors. But now, because she's developed into an adult, it is a lot harder for her because there are less categories to choose from now.* *- I think every athlete struggles with their weight, let's be honest. I mean, you don't train at your fighting weight.* *- I would rather my daughter be in a weight category that she is suited for. She's not suited for -57 kilo because she's too small so I'd rather have her in a weight group where I know she's going to come up against other athletes that are roughly her size because at the end of the day, she would get kicked left, right and centre.*	*- The most that she's ever needed to lose is about 4-5 kilo.*	*- Well it's normally like once a month isn't it, you've got a competition coming up at least 12 times a year.*	*- It's normally about 3-4 weeks before she'll start really, really getting her weight down.*
		Parent 5	*- My son to be fair, he never really had to lose weight growing up and we didn't really want him to but now obviously he's a senior it's a necessity.* *- I think it's a given that normally you are walking round at a few kilos heavier than the weight you're competing at, that's just a given of the sport.*	*- I'm not saying he never had to lose any weight, there were a couple of instances where he may be lost up to a kilo and a half, 2 kilo tops as a cadet and junior.* *- He's been selected for senior world championships as a 63 so like 7-8 kilos now maybe?* *- I've seen juniors cut 4, 5, 6, kilos…that's just wrong.*	*- Well he competes very often now. He tends to make weight at least every few weeks so up to 12 times per year.*	*- He loses it slowly now. Yeah, probably about 3 to 5 weeks, something like that. As a cadet and junior he'd do it in about 2 weeks or so.*

APPENDIX 3.2

GROUP	SEX	PARTICIPANT	BM LOSS METHODS	PHYSICAL SYMPTOMS	PSYCHOLOGICAL SYMPTOMS	BODY IMAGE & PHYSIQUE
ATHLETE	**FEMALE**	**Athlete 1**	*- I'd do fasted cardio in the morning as that helped me a lot, sort of train before breakfast.* *- Dehydration was a massive part of my diet plan. I'd probably dehydrate a day or two before the competition.* *- I'd have to use the sauna.* *- The last two days before I was training in a sweat suit. We train two or three times a day and I'd probably just wear that for the last two days.* *- The day before the competition I'd have no fluids and obviously the day of the weigh in I'd have nothing.*	*- The last two days when I wasn't eating and drinking much, I would be the same, I'd be really fatigued and I wouldn't feel like I was getting the most out of the session just because you'd feel dizzy and really fatigued. It was so hard on my body.*	*- It was really difficult actually, like it was really hard. I think after a time I did get used to it but, yeah, it was really hard.* *- Yeah it was really tough and I couldn't hack it anymore so I left the national team.*	*- No. For me at the time it was just about making the weight. I didn't really mind how I looked. Obviously I was very skinny then and yeah that wasn't as nice, but it was mainly just about making the weight for me.*
		Athlete 2	*- So the first phase would just be cutting the carbs and continue training as normal and then the last week or so, start dehydrating from there.* *- More layers in training, so, more clothing, using stuff like sweat suits, restricting water intake during training, just trying to increase the sweating and more out rather than in.*	*- Tired, fatigued, quite slow, sluggish when I'm training.*	*- Fucking tough. Quite a lonely and demoralising process.* *- Mentally just not motivated, not enthusiastic.* *- I get mood swings quite often when I do the diets. I start snapping at people and getting quite upset, just over nothing, breaking down crying for no reason.*	*- Personally no, I don't concentrate on looking good as in like physical appearance but more performance.* *- Sometimes I'd look really, sort of drawn. I didn't look alive should I say, almost like a corpse.*

ATHLETE	**MALE**	**Athlete 3**	*- The training increased, the intensity increased.* *- I used to gradually week by week reduce my carb intake.* *- I'd gradually bring meal sizes down and cut the pasta and rice out of it and it would just literally be protein.* *- About three days before the competition I'd dehydrate myself quite badly. Every now and again, when I was trying to lose a lot, I used to go in a sauna.*	*- Awful. Absolutely disgusting. It literally made you question why I competed every time I did it.* *- The week before a competition, training was pretty much non-existent, you just turned up because you had to, but you'd sit out most of it and not do much.* *- It used to affect my sleep quite a lot. Sometimes I'd only get 3 to 4 hours' sleep.*	*- Mentally it doesn't put you in the right frame of mind to be fighting and sometimes on the day, you'd just be no good and dehydrated.* *- I guess like most athletes you kind of just got on with it. You just learnt to accept things and it became normal.*	*- No it was just about the number on the scales at the end of the day. I mean to be fair, I didn't really like the way I looked at 63s, my face went quite drawn in and I lost a lot of muscle.*
		Athlete 4	*- When I knew it was a competition period I would slowly reduce my carb intake from maybe 75g down to 50g and then the last two days be about 25g and literally the last day it would be none.* *- If I had to sauna I'd only do it on the day of the weigh in so I wouldn't mentally be in that dehydrated zone like before, I would always do it on that day of weigh in because it is a really big mental push to do it the night before as you've got to sleep.*	*- You literally have no energy whatsoever because obviously all my energy storage has been depleted and it was so hard to train.* *- Yeah it was such a hard push, like obviously getting into the sauna when you're dehydrated is like, it just feels like your body is dying, getting dizzy, it was a really big push.*	*- Obviously you see people in the sauna drinking water and you're sat in the corner like just looking at them but it was a really big ask and mentally, it did mess you up in the head. Sometimes no matter how hard I tried not too Id break down.*	*- Well, obviously when I do make 58 kg I do want to look like quite lean, but then for me personally, it doesn't really bother me if I look shredded or anything. I just want to make the weight.*

ATHLETE	**MALE**	**Athlete 5**	*- So I would typically start dropping out carbs, definitely in the evening.* *- I would start doing some kind of cardio sessions in the morning before breakfast.* *- I'd probably drop down to like 800 kcal a day.* *- I'd start cutting down my fluid intake 48 hours from weigh in and the day before the weigh in I'd just drink little espresso shots to dehydrate me a bit more.* *- Last training session I'd wear my sweat suit, and a few layers to try and just lose as much as possible.* *- The day of the weigh in and a few hours out probably 50% of the time I'd just hop in the sauna in the morning.*	*- The last week I'd often feel if I sat up too quick I'd feel dizzy and not black out but do you know what I mean, when your eyes glaze over.* *- I couldn't maintain training intensity for any longer than 5 minute intervals…it was hard, very, very, hard.*	*- It just consumed you, like all I'd think about, probably 90% of what was on my mind would be related to weight in some kind of fashion. I'd be thinking I can't obviously, the eating element I'd be thinking I've got to get to bed early, try and burn off some more calories as opposed to staying up late and messing myself up. Everything was kind of related back to weight as opposed to just living life.*	*- Not really, no, I don't think so. I think I didn't like when I ballooned back up again, I looked a bit chubby, but cutting down it wasn't on my mind to be honest.*
COACH (previous competitor)	**FEMALE**	**Coach 1**	*- I've certainly done it badly myself and I've felt like shit as a result of doing it.* *- Because mine aren't coming down a lot they tend to cut the crap in terms of what they're eating and then do some extra physical stuff, go for runs, slap on a few extra layers by all means but I don't like them dehydrating. I wouldn't let them sit in saunas.*	*- When I did it I just felt drained and I found I was focussing more on the weight loss than the training and the performance. That's why I won't let mine do it.*	*- All I could think about was 'I can't wait to weigh in, I can't wait to eat something' and I don't think it's ideal preparation. I think you need to be focussing more on your game play. It's a bad place to be mentally prior to fighting.*	*- Looking at my current lot, they're all skinny, they've all got brilliant six packs but it's just something that's happened rather than, you know, 'we've got to hammer it, we've got to get that' you know what I mean?* *- At the end of the day it's about making the weight not looking like a model.*

COACH (previous competitor)	**MALE**	**Coach 2**	*- Well, what they should be doing and what they do are two completely different things I think [laughing].* *- My guys will gradually diet and increase training…it's all about in versus out you know?* *- I mean, I did have one athlete that turned up to the last World Championships that was 10 kilos over and had to make it in 7 days.* *- I know athletes that will use a sauna, will dehydrate, will not eat for seven days, properly beforehand and just eat bits of fruit and water. That's common practice in Taekwondo.* *- I don't like them dehydrating but they do it…saunas especially.*	*- I think when they're dehydrated and they've made weight, their focus doesn't seem to be the same.* *- You see the focus isn't quite there and you can see the sharpness and even the movement, there's a lethargicness about them I find, when they've had to do that, especially in the latter parts of training.* *- When it comes to sparring they struggle to survive really.*	*- Well there's a level of stress, I think, that's associated with making weight.*	*- For me it's functional muscle that I'm more interested in, you know, you can have a six pack and you can look really muscular but is it functional for the game?*
		Coach 3	*- In the past a few of mine and others have done crash diets, not good, saunas, last minute preparations causes problems.* *- The senior athletes will do things like not drinking, exercising a lot more, saunas, sweat suits, and then last three days crash dieting, not eating…fucking madness!*	*- They make the weight and are then relieved but they have no energy, even when you give them a recovery period of a day, they still can go out there and the energy's gone, it's sapped the energy doing all that crazy shit.* *- Tiredness in training. Yeah, definitely tiredness, fatigue, lack of energy, they can't communicate, just want to sleep.*	*- Mentally they're just not there. It's like their focus is in totally the wrong place it's on the fucking scales when it should be on the competition!* *- Sometimes serious depression in terms of being really, really morbid.*	*- No, no, I don't worry about the physique in terms of how they look as long as they are healthy and can perform.*

COACH (non competitor)	**MALE**	**Coach 4**	*- To be fair, usually we try and go with just better choices with meals. So you know, healthier options.* *- In regards to dehydration we tend not to do it. Not eating or drinking for a full day with juniors and cadets is just not good.* *- With senior, yes we have done dehydration before but that’s a senior, they know what they’re buying into. They can give you a little bit more context, you know.*	*- Dehydration of 24 hours may have a real detrimental impact towards a performance in a competition. In regards to fatigue, just like, first match and recovery from the first match and not being fresh.* *- I tend to see the ones who do it badly get ill, catching colds and stuff.*	*- Those who do it badly just aren’t with it you know? They are like ghosts mentally just not in the room.*	*- The real main important thing to me is kind of (a) are they healthy, (b) are they performing? The general looks of the athlete’s body, obviously if they are skin and bone it’s a problem, you want them to look lean, you don’t really want bones showing here, there and everywhere, but at the end of the day they need to make the weight.*
		Coach 5	*- I just advise reducing portion sizes a little bit, don’t let them snack in-between meals, because they do and don’t have any carbs after six o’clock. Simple really isn’t it.* *- The seniors do something that’s a bit more crazy and personally, I have to turn a blind eye to it, from sitting in a sauna which some people do to training in it in layers. I know one of them was taking water tablets before which is not great.*	*- It makes them tired in training, their reactions aren’t quite as quick, and they can’t concentrate as well.* *- They don’t have any stamina the next day, you know. Normally they’d be able to do three rounds of 2 minutes and at the end they’re a little bit tired and sweaty and breathing, you know, losing their breath kind of thing but then within 20-30 seconds into the match, they’re acting like it’s the end of the third round. Losing the weight fucks them up in the ring.*	*- I’ve seen athletes from other clubs break down. They literally just mentally lose it which is quite scary really.*	*-Well for me, to be successful in Taekwondo generally speaking, you’ve just got to be tall and skinny, that’s the physique, that is the winning formula.* *- Six packs and stuff not important to me whatsoever. They need to make the weight and be built in the right way to perform.*

PARENT (Taekwondo)	**MALE**	**Parent 1**	*- I'm sure there are occasions where they're just not eating enough and, you know, they probably, even if they make the weight, they can't perform to their best because of that.* *- So she'd only be one or two kilo and she could usually do that mostly with a bit of dehydration in the lead up to the weigh in.* *- I remember I weighed in at 54 kilos and fought at the World Games in London and next day I was 59 that night. I put on 5 kilos in 24 hours and even then I knew it was wrong and I said to myself 'I'm never doing that again'*	*- Sure I've seen some drastic weight loss over the years, they start off okay but they just become listless.* *- The other thing you see is when people have dehydrated far too much or starved themselves, then as soon as they weigh in they take on board too much water and try and put it all back in a short space of time and end up making themselves sick, you know.*	*- I should imagine but anything like 3-4 kilos and some people doing it in a week, it's going to have a big effect on their mental wellbeing*	*- I don't think the way they look ever comes into it. You need to make the weight and perform.*

PARENT (Taekwondo)	**MALE**	**Parent 2**	*- It was a given that a couple of those kilos would be in fluids the last week or two weeks, well it's normally the last week, was just fluid really and that was it. It was just sweated off.* *- Certainly in the last two days, last three days before a competition, definitely the last day, you'd really cut the fluids out.* *-Sweat suits, saunas, we didn't really do hot baths.*	*- Tiredness, fatigue is the main thing, I would say, I mean this shouldn't really apply to mine because it wasn't really an issue but when I have seen it happen, slow cognitive response as well, when they're really dehydrated, I've noticed, it is a bit slow.* *- I tell you what did interest me, what I was going to ask you about, does this put any strain on the heart, you know and stuff like that because a few of them would complain about chest pains?*	*- Psychologically it's just not good when they go extreme. It just takes all the fight out of you doesn't it.*	*- Not the way they look, not at all. I'm not interested in that only their game. Obviously because of the way the game is tailored now, the taller player has an advantage if they've got a longer leg length.*

PARENT (non Taekwondo)	**MALE**	**Parent 3**	*- I always call it controlled eating but you cut out the eating rubbish, you make sure they're eating healthier, you steer them towards more smaller portions and then, to be honest, the last kilo or so is normally dehydration, you know, on the day or 2 before.* *- So over that last few day period they'll take minimum intake of food and fluid.* *- To be honest, some of what I have seen has shocked me to the core. I've seen extreme stuff, people using water tablets, people using laxatives, you know, just to drive the weight down.*	*- They're drawn in their faces, you know, as it's coming out of them.*	*- It's a mind-set that they know they're going to be losing weight to compete and that's what they do.* *- It just seems to be a thing now for any group of Taekwondo players that there's a level of 'oh I'm cutting weight' or 'yeah I'm fighting in three weeks' or 'I've got three days to weigh in'.*	*- The physique's not important. So it's never been a body image, I want my kid to look like whatever, it's I want my kid to be there in the right frame of mind and healthy.*

PARENT (non Taekwondo)	**FEMALE**	**Parent 4**	*- She needed to lose 5 kilo within a state of 3 days between two competitions, that was like training and a sauna and couldn't hardly eat anything.* *- I've seen some who obviously don't make the weight and they're only like 0.1 or 0.2 over and they're still having to run to make that weight in the last hour or so.* *- Obviously there's the dehydration isn't there which is more of a concern for my daughter because she suffers with really bad migraines and then she'll up her training but she'll also take an Epsom salt bath, maybe two days before she's due for a weigh in.*	*- Just drained, absolutely no energy to do anything even speak at times. It used to play havoc on her period sometimes if I'm honest.*	*- It is mentally draining as well and you know 'I can't have this, I can't have that' and I mean, I've seen my daughter sit there and literally not drink anything, just swill water round her mouth and stare into space like a zombie.*	*- Taekwondo players, they're all literally near enough the same physique. They've got wide shoulders, small hips and you know, quite slim legs. For me it's important for my daughter to look like this but not at the cost of killing herself for it.*
		Parent 5	*- I think basically when they're juniors, often when the juniors did it, they basically just starved themselves for days and dehydrated, you know, because they wouldn't do it gradually. They would leave it up until, the last week or so and then suddenly try and cut 4-5 kilos just by basically not eating.*	*- Well they're just drained. They just do not seem to have any energy whatsoever in the ring and it's a waste of time. They've lost that much weight, they're that exhausted it's a waste of time and to be fair, I think it's more dangerous than going up to the next weight group.*	*- This has never happened to my son but I've seen break downs. Just full blown mental breakdowns which is frightening when you think about it.*	*- It's difficult for me because he's always been slim and just always been a natural athletic build. I mean to me, it's up to the individual to make the number on the scales no matter what isn't it, you know what I mean?*

APPENDIX 3.3

GROUP	SEX	PARTICIPANT	NUTRITIONAL PRACTICES POST WEIGH-IN	NUTRITIONAL PRACTICES COMPETITION DAY	NUTRITIONAL PRACTICES BETWEEN COMPETITION PERIODS	PERCEPTIONS ON NUTRITIONAL KNOWLEDGE AND PRACTICES
ATHLETE	**FEMALE**	**Athlete 1**	*- So obviously getting the fluids back on was really important. You'd have the re-hydration packs that you put in your drinks, I'd have that and obviously fill up on carbs like pasta just to get full again for the competition the next day.* *- Sometimes I was so hungry that I'd binge out and that would make me the next day feel quite, you know, heavy and sick to my stomach.*	*- I'd usually have porridge in the morning when I wake up and then protein drinks and stuff throughout the competition. A lot of water, I'd have carbs and fluid was the main thing I think, yeah.* *- So your stomach shrinks because you haven't eaten for a few days so fluid was the most important thing for me.*	*- The first week or two after a competition I would sort of go crazy and that wouldn't help. Strange thing is I don't know why, my body would just crave things, I'd be eating without realising it was weird! But then, after that week or two period I'd go back to my diet of like, no snacks, three meals a day sort of thing.*	*- Time as well as cost…after training, when you're tired, trying to cook, that's quite hard, making and preparing meals at the beginning of the week and then freezing them.* *- I'm quite happy in my nutrition but maybe choice of what I could eat because like I say I would stick to chicken and veg because it was easy, it was quick. Maybe like different choices, because I used to do it in grams. I'd have a certain amount of grams of protein and then a certain amount of grams of … but maybe the same amounts but a different choice of food, if you know what I mean. Make things more interesting!*

ATHLETE	**FEMALE**	**Athlete 2**	*- I drink as much fluid as I can get my fucking hands on.* *- Find the nearest place to eat, whether that be McDonalds, restaurants and just get food and drink straight away.* *- Burgers, pizzas…all that shit. You are starving! That was purely it. Just totally drawn by it* *- Usually it is just like motivation, almost like your body is calling out for it.*	*- I don't usually eat on competition day. I might have breakfast, a bit of toast or cereal if that's available but not a lot to eat during the day. Just water really.* *- I think it was just down to nerves. I've never associated with eating on the day of competition with performance, sort of thing.*	*- Quite relaxed, so, it would vary from making food in the house so like chicken curries and the next night junk food. Yeah, high sugar foods, chocolate, crisps.* *-I'd say it goes downhill even more so in the off-season. I just sort of pig out at Christmas, loads of chocolate, Coca-Cola, alcohol. I don't really want to think about making weight in this period until I have too.*	*- Yeah. I perceive carbs to be, what puts the fat on basically. So no or low carbs during training camp.* *- My coach. They used to give me, sort of the foods I can eat, certain meals and stuff like that.* *- Well yeah, it is expensive to eat healthy. It's probably partly the reason why it is usually 2-3 weeks before, it's to lower that cost a little bit.* *- No it was just eat it because I wanted to make the weight. All that mattered was just the number on the scales.* *- My nutritional knowledge is shocking if I'm honest which is stupid really considering that's what will help me make weight.*

ATHLETE	**MALE**	**Athlete 3**	*- Id drink so much water but to be honest overall not great. My routine would be I’d go to some sort of supermarket on the way to weigh in, make like a couple of sandwiches, I’d take a pack of biscuits or chocolate. I even got to the point sometimes I’d make cold pizza and take that with me. You know what it’s like when you’re starving, you want all the stuff you’ve not had for weeks.* *- So it was kind of crammed, I used to not sleep the night of a competition because I’d probably over carbed or had a sugar rush or what, I don’t know. It just used to make me feel sick.*	*- I’d keep drinking plenty of water and I’d usually try and have a bit of breakfast. I always struggle to eat, to be fair, on the day of a competition so I wouldn’t have a lot of breakfast.* *- I used to get really nervous on the day and I couldn’t eat. I used to try and have protein shakes and stuff and you know gelatine stuff, like wine gums, sometimes I’d have Jaffa cakes, I could never really eat a full proper meal.* *- Like short release energy foods. So I’d try and have it like half an hour before a fight or something daft like that.*	*- Average. I mean I do like healthy food. I would eat chicken and salad and stuff but there’d be a lot more carbohydrate in there. Obviously I’d have some junk food and stuff. My biggest downfall is chocolate and biscuits. I eat a lot of that. Obviously then you’ve not had a night out with friends in a while so you have a big blow out which obviously involves a lot of alcohol and a lot of junk food. So I would eat, it would be a bit of a mix, really poorly and with some good food in there as well.* *- You deplete yourself of so much for weeks, you just want it, you don’t even need it but you want it it’s hard to explain.*	*- I’d say it’s more cost and time. I always find eating, I love fruit, like fruit smoothies and stuff like that but it’s just expensive and I need time to make them.* *- I’ve got a bit of a basic knowledge about it, but I think motivation’s a big key to be honest. Something I don’t have a load of knowledge about, how to do different healthy meals.* *- I wouldn’t say it’s good, I’d say its average which is why it’s more frustrating that I don’t do it properly because I do know it’s all wrong. I mean I class good as someone that, probably like yourself, that has done a lot of degrees or whatever in nutrition.*

ATHLETE	**MALE**	**Athlete 4**	*- Obviously I want to take on fluid in those two hours after weigh in so I can start taking on some food. So that night obviously I will indulge in some carbohydrates so I would have rice or some pasta.* *- I've seen athletes eat straight away and I'm like 'shit, you're going to get fall out', that's what I did starting out, I did used to get really full and feel sick.*	*- In the morning I always have some porridge, to get me throughout the day and I will constantly keep drinking to keep myself hydrated. Obviously I've been dehydrated so I want to drink as much water as I can and some fruit, like sugary snacks and energy drinks. Sometimes I would, try a Red Bull to keep me awake throughout the day and obviously have some jellies in my bag for the competition plus more carbohydrate intake and maybe like a light chicken sandwich eaten throughout the day, if I've got space in my stomach.*	*- For a few days Id binge on crap food. I just couldn't help myself it was as if my body was calling for it. Then I would convert back to protein and vegetables so I never try to go above 61 kg. If I did I always knew it would be a lot harder for me if I saw that my weight rebounded back to about 62, 63 kg and I was like it's going to be a lot harder to drop my weight if I'm competing in the next three weeks.*	*- Nutritionally I do anything to get down to that category. I had to eat certain foods which obviously were light and which was a lot of lean meat which could actually get you into that category. If it was the other way I'd be smashing pizza all the time [laughing].* *- Yeah well as I said earlier reduce the carbs pre weigh in and ramp them up after.* *- My nutritional knowledge…probably not the best I'd say! I know I need to know more about it and make better choices but it just takes up a lot of time and to eat like that constantly isn't cheap!*

ATHLETE	**MALE**	**Athlete 5**	*- Re-hydrate very quickly because I'd try and get so many fluids in me, as quick as possible. I'd always have like a re-hydration drink of some kind first and then I'd just kind of sip on water to get the fluids back in me. I'd try and have plenty of carbs, in a big but healthy meal. I'd do that and then often in the night time just, as a mental reward, I'd give myself a treat like a chocolate bar or something.*	*- Again, on comp day drinking lots. I'd have a coffee about half an hour to an hour before the fight or some caffeine, some form of caffeine anyway and I'd just eat small and often during the day.* *- A lot of low fat, high carb things. I'd have, if it was like a lunch break or something, I'd have something a bit more substantial like a sandwich or something…the key is just get the energy back up isn't it that's why carbs are good.*	*- I'd binge at first, to be honest, when I got back I would eat everything I'd been fantasising about I suppose, for a week or so and then I'd just get back into my normal routine, just general healthy, reasonably healthy kind of trying not to worry about it too much. I knew how focussed I'd been on it, once it got to the back end.* *- I'd have lots of different things, sometimes I'd just have a reasonably healthy ready meal, just something quick. Dinner I'd often eat out, so quite varied. Eat out or order in, just like some grilled chicken wraps or something.*	*- I think a lot of it was down to peers. Everyone in my house was making weight. Everyone was cutting, to some degree, anyway. So we were all kind of in the same boat so they were all making joint decisions. We didn't cook together but if we were going to go out to eat or order something in, it would be kind of a group decision.* *- I 100% know the right things to be eating and when to be eating. I definitely know, kind of, all of that stuff. I think sometimes it is just about putting it into practise, that side of things sometimes I was kind of lacking.*

GROUP	SEX	PARTICIPANT	PERCEPTIONS OF NUTRITIONAL KNOWLEDGE AND PRACTICES	INSIGHTS ON CHANGES TO BE MADE
COACH (previous competitor)	**FEMALE**	**Coach 1**	*- Well they should have the knowledge, I mean I help them out with what they should be eating and I look at their diets, if they're trying to come down a little bit then I try and swap things over. Half of mine would still much rather have a McDonalds than a salad. So the knowledge is readily available but they don't tend to follow it very strictly, in my opinion.* *- I'm not sure that they get the correct advice. I try to give them advice from my experience 'don't come down, don't go in the sauna, don't dehydrate …' They, you know, some clubs, I don't think they give them any advice at all. The national team gives the juniors and the cadets these info slides and stuff. They are getting the knowledge there but that's only when they're at a certain level.*	*- I mean, they're given decent food when you go to a national camp. They give them the right sort of things to eat for their training, etc. but they come back and say 'oh, that was awful' [laughing], 'can we stop at McDonalds on the way home'.* *- I think as they come up to seniors, they mature a little bit and they realise that the crap diet they've been following isn't necessarily the best. I think they take it on board and change it a little bit more.*
	MALE	**Coach 2**	*- Nutritional wise, even at elite level, and this is something that I see, is that they've got a routine that they've had and they've probably had it for ten years where they're doing quick weight loss to start off with. They make their weight and they binge afterwards which is not good, you know, and you look at the stuff they're putting back in their body. I guess due to budgets as well, they're not even eating properly. So, I think, for them, it's more about making weight, it's not about how they make the weight and it's not about is this going to be good for them? Or is this going to help their performance? So I think their knowledge is very limited.*	*- I think the coaches need more guidance. If you're looking at a cadet, junior, anyone under 18, you are influenced by your coach, by your peers and parents, so if the advice you're getting is wrong at that age, that's habit forming and what happens then is that you then think 'that's the way I'm going to do it' and what happens is that player then becomes a coach and he will then use the same methods he's used for his athletes.*
		Coach 3	*- For the seniors it's nice for them to be educated around nutrition but when they're younger their general health is dictated by the parent and what they're doing at home. So, education would be good but it's not going to have a major effect on their performance when they're young but when they're older they need to be a bit more healthier, look after yourself more etc. When they're younger, I mean, education is key but I don't think it would be that important to enforce that to them unless they're being told by someone from an organisation or a coach that they must make weight by losing say 8 kgs.*	*- I think it has got to be a mixed bag, especially in the younger groups, too much dictation of policy will not work with 12, 13, 14, year olds so you might have to do more interaction or co-ordination games for interaction but for the seniors you can do policy procedure, splitting facts, you can have a presentation on the best way, what kind of foods etc. and also, having athletes coming in and talking about their past experiences.*

COACH (non competitor)	**MALE**	**Coach 4**	*- I'm mindful of the choice that they make. I think they do alright, they try. If you say 'try this', they try. What we tend to do is instead of making a massive change we'll just make one change, you know. I don't think there's enough knowledge above the coaches because a coach, unless you've got a degree in nutrition like you, a coach can only give so much information.*	*- I think there should be somewhere they can log into or somewhere they can access information easy that just like some FAQs, you know what I mean, just general advice.* *- I mean anything is better than the national team weight making policy...I think it's a load of rubbish [laughing continuously]!*
		Coach 5	*-No, I'm not happy with the choices that they make. Despite the fact that they have all had various nutrition workshops with the national team, although to be fair the nutrition workshops I think are a bit boring. I think there's information overload. They talk to them like they've got a PhD in nutrition, I think it's far too technical and complicated. Even with that knowledge I still think they make poor choices. So they will try their best to eat Haribos all day during a competition rather than eating sensibly, you know.*	*- I think the coaches do because it is the coaches that reiterate and support everything that's happening because otherwise if the advice from a nutritionist is for the kids to eat a Nutrigrain bar in the morning and have another one at 10.00am and another at 12.00, if the coach, isn't aware of this, they might take the piss out of them for eating it or they might say 'stop eating, you're always snacking all the time, you shouldn't be eating that' you know what I mean?* *-I would like to add that I think frankly, the national teams approach to making the weight policy is disgusting. I think it is appalling how they have made certain athletes kill themselves to make weight categories for events. I just think it's appalling and they should be more responsible.*
PARENT (Taekwondo)	**MALE**	**Parent 1**	*- We did okay when it was just the two of us and I was coaching her as a junior and just starting out in seniors and then the nutritionists and stuff took over so she had a good education and she knew what she was doing. I've come across a few of my athletes who have gone about it the wrong way but because of the experience with my daughter, I have tried to pass on as much information as I can.* *- So you can educate people but you can't always guarantee that they're going to take it on board.*	*- Well getting professionals like yourself to do talks and presentations to the athletes themselves, that'd certainly be a start.* *- If you hear it from a professional and you've heard about what the dangers are, what can happen I think then it will start to sink in and maybe iron out people who still have bad practice, possibly.*

PARENT (Taekwondo)	**MALE**	**Parent 2**	*- With my son and other athletes their nutritional knowledge is fine to eat well I believe but funnily enough I was looking at supplements and things like that yesterday and I was thinking I need to get back on this because I know jack shit about them. But ultimately this is where the coaches need to be educated, the kids won't know what to do, it's got to be the coach and parents and so this is where that is really important for me, to bring it out.* *- You never get a bad player, you get a bad coach and so if the coach is not relaying the right information it is going to go down into the players. The coaches need education, that's 100%. That change needs to happen because the club level coaches is where it starts with the grass roots and I would take a guess that 99% of the coaches in this country and I'd put money on this, have no clue about what advice to give them on how to lose weight and how to, you know, eat nutritionally.*	*- It's simple for me and I've mentioned this before, I would go through the website, I would have a nutrition section. I would state that from grass roots level to national level and then to international level I would simply stage that and list, the type of nutritional stuff you need to be taking on.* *- I was like 'yeah well sports science is alright, you know, it doesn't make that much of a difference' well I have a totally different outlook now. I think it's a really important tool for an athlete and so that's probably what changed my mind.* *- We need to do something soon though or I'm telling you another player is going to die like that Turkish kid at Egypt Open or that Cuban boy recently.*

PARENT (non Taekwondo)	**MALE**	**Parent 3**	*- I just think generally I feel in Taekwondo, not just with my children, I think with any participant, it's a strange that as a weight defined sport there is no effort to push out enough nutritional advice. It's almost to the point where the key thing to any Taekwondo event is weigh in. I think there should be something tied round weigh in, whether it's having somebody there giving nutritional advice, even if it's just a handout sheet of nutritious foods and you know, it's now a weight conscious sport but the nutritional education for competitors, as children, or parents and for coaches, just seems to be missing in the majority of the cases.*	*- I think that we really, really need to start at the top with coaching. I think a lot of coaches need to understand the nutritional advice should be given a lot more. There should be some medium where maybe by region that parents are actively educated as well and then thirdly I think, again, there's got to be some way of driving that, whether it's, again, some type of nutritionist or someone with a sports science background, actually going round clubs and talking to the players and letting them understand. Then, at least, in my opinion whether we like it or not the weight loss thing's here to stay so at least let's get some education out there. Let's have parents, coaches and athletes making informed decisions rather than what I see today.* *- Ultimately though all of this should be driven by the world federation, it should be driven by them to say, you know, 'these are the weight categories, this is our expectance, this is our tolerance' and change the weight categories appropriately for the global population.*

PARENT (non Taekwondo	**FEMALE**	**Parent 4**	*- Well to be fair, she knows what she should do but whether she does it or not obviously that's down to her. But when she was training normally there was no information there, as I say, for her for what she should eat or what she shouldn't eat. It was just sort of like a stupid fad thing or you know, 'just eat fish with tomatoes' or something. There really isn't enough out there, the coaches didn't explain to her enough about nutrition.*	*- I think the best way, firstly is you want to get in touch with all the coaches don't you and you want to run it through with all the coaches first so then hopefully they're going to go back and feed it down to the parents and then you either decide whether the parents feed it back to the kids or the coaches feed it back to them. But I do think the nutritional side of it needs to start with the coaches because at the end of the day the coaches will coach but it's always there, it doesn't end with just sitting in a chair and telling your kids what to do. It's everything, its nutrition, its attitude, it's absolutely everything and it's not just teaching somebody how to kick.*
		Parent 5	*- You were basically on your own from a nutrition standpoint, unless your parents or coaches knew something about it or you paid to take them to professionals, like nutritionists and dieticians, otherwise you didn't have the back up, they were just basically making that weight and they were left to make it.*	*- No I wouldn't be happy if my son were told to make 58s that's something that I don't agree with anyway. In my personal opinion it is ridiculous those Olympic weight categories, that you fight at a certain weight category at every other competition bar the Olympics and then it's, you know, their stupid 10 kilo differences between weight categories. In my personal opinion it's ridiculous and the world federation should really be trying to get that changed.*

APPENDIX 3.4

GROUP	SEX	PARTICIPANT	INFLUENCES ON BM LOSS & NUTRITIONAL HABITS	SUPPLEMENT USE AND ANTI DOPING KNOWLEDGE
ATHLETE	**FEMALE**	**Athlete 1**	*- Well it was partly me and my coach.* *- Obviously the weight up from that is 57 kg and (another competitor) was in that, so my target was to make 49 kg.* *- We have targets to make every week and that was a massive influence, that I'd want to make my target and then other fighters in the same weight as me, if maybe they weren't doing so well on their weight but you were, maybe you'd be picked for that competition and stuff like that.* *- Obviously living with other team mates who are also dieting so we can cook together, eat together, we were like a little weight cutting club [laughing].*	*- I'd take like iron tablets and multivitamins things like that.* *- Yeah I'd have protein shakes as well and like protein bars.* *- I went through a stage of taking β Alanine.* *- Global-Dro. I'd go on to check to see if it is legal to have and yeah, that was on us to do. It was literally just check it yourself. I never really had much knowledge on the signs and stuff.*
		Athlete 2	*- My coach, he wants for me to be as low as possible, obviously due to his understanding of the height and weights, he finds it best for me to be as low as possible in that respect.* *- Obviously there's taller, bigger players in the higher categories so you're more likely to get the smaller lighter athletes in the lower categories and with myself being small I go down.*	*- No I've never taken supplements.* *- Just not having the knowledge of them plus a little bit the doping side of it, knowing what's classed as doping and what isn't. The cost of some of the stuff available isn't cheap either.*
	MALE	**Athlete 3**	*- Yeah, it's like the normal thing to do, everyone does it. Your coach tells you to do it, all the national team athletes do it so you accept it.* *- I literally had, even (a national team coach) at one point told me to go down to 58s and I was just like 'I just can't do that'.* *- Not friends or family because all my family hated me doing it. Team mates, me and my cousin are quite close, we used to do it together a lot. My coach never really, like, give me any other advice about it all he just said is its important.*	*- I've never really taken supplements.* *- What I used to do when I was trying to cut weight again, I'd have meal replacements, I'd have like a protein and oats shake, that's kind of the only thing I've ever used.* *- I have no idea about what is tested or isn't or how to check for it. Not a clue to be honest.*
		Athlete 4	*- I think as my team mates were making 58, I'm quite close to them and obviously we know it's hard so we did motivate each other to get down to that weight category and we all did struggle together but I think, yeah, it was an influence that if one's making it we all try and make it, we all try and push each other to make that category. So I'd say, yeah, team mates were a big influence.*	*- Yeah well electrolyte tabs and stuff like that plus carbohydrate/protein drinks after weigh in.* *- I've taken β Alanine.* *- Generally I was always told it's my responsibility and so I'd check Global-Dro.* *- I have no idea what Informed Sport is to be honest.*

ATHLETE	**MALE**	**Athlete 5**	*- I just thought, like, as long as I make the weight I'm physically bigger, technically as good or better kind of than anyone in the weight, so, that was my thinking really. I was kind of my main driver. I guess selection policies and Olympic weight categories don't help though.*	*- I used to have creatine when I was at 74 kg. I've also had β Alanine, is that how you say it?* *- I'd have a lot of energy gels and bars things like that after weigh in.* *- Yeah. I was very kind of keen to make sure it was all off the list. Id check on that website, what's it called...Global-Dro.*

GROUP	SEX	PARTICIPANT	INFLUENCES ON BM LOSS
COACH (previous competitor)	**FEMALE**	**Coach 1**	*- Well within the national team it's the coaches and the pressure to perform at the weights that they're selected at because one of my athletes been told that she's got to make 57. She's never played 57 in her life and she weighs 62 and there's absolutely zero fat on her. They're adamant that she can lose 5 kilos, I'm not convinced.* *- Yeah, parents do have a say in it. I tend to say 'I'm the coach and we make the decisions, you don't' but they're always piping up about it aren't they? They'll be looking at a category and stuff, and they'll say 'get down to there because it's much easier to win in that one than that one, she's massive etc.'*
	MALE	**Coach 2**	*- I think it's the coach because the parents normally don't have a clue about nutrition and so I think the coach has that influence there and I think possibly even with juniors and seniors, they'll probably look at it because they'll have a better idea than the athletes.* *- I think there are a lot of influences with under 18s because they're influenced by a lot of people. They're influenced by their peers like I said, other athletes and sometimes, if I'm being honest, parents. It's crazy how much a parent can motivate their child to make weight it really is.*
		Coach 3	*- I mean coaches have an influence because we pick and choose who our athletes are don't we.* *- It is the national team who put the pressure on Taekwondo athletes across the board. Maybe that's directly by saying it by things like 'you're too small for the weight, you'll have to go down' or, 'you're not going in this weight, you'll have to go in this weight'.* *- Parents are a big influence on young kids I get that and the coach is more influential when you're older.* *- Coaches and parents have to push it to get their kids recognised and to be picked for the national team.*
COACH (non competitor)		**Coach 4**	*- I think at cadet and junior level the parent plays a massive part because they either make or break an athlete. They either push them to a point where it's just, it's wrong, so I think sometimes it's the parent that has the main kind of pivot on them.* *- Selection criteria at national team level I think plays a big part in it. But it's more of the coaches and the parents that will probably say 'I think we should apply for this weight because of X, Y and Z'.* *- I think at junior and cadet level you can only advise, put your cards on the table and say 'this is what I think is the best option and this is how we're going to do it' so the parents can take it or leave it.*

COACH (non competitor)	**MALE**	**Coach 5**	*- I think the athletes parents to start with but once they start competing at seniors it's more a coach athlete decision. Yeah, because the coach will say 'I want you to fight in -59' or 'I want you to move down to -55, do it because of these reasons'.* *- I don't think it's the selection policy, well, perhaps it is but it is just the opposition isn't it? You know that someone's better than you so do you compete with them and lose or do you move to a different category and be successful?* *- I do myself but more from a positive perspective, so that I'm saying to an athlete, 'I need you to keep under 60 kilos, for this particular competition because in six months' time we need you in the same weight category'. The person that puts the food on the table in that house is her mum so I need to engage with her mum to make sure that she is doing as she's told [laughing].* *- I wasn't able to give any more advice out which frustrates the hell out of my students because they look to me for knowledge and experience and even if I was a qualified nutritionist, the safeguarding authority have said I'm not allowed to give that advice because I am a Taekwondo instructor, which is bizarre, in all honesty.*
PARENT (Taekwondo)	**MALE**	**Parent 1**	*- I spend a great deal of time trying to encourage the parents to let the kids compete at the next weight up but they all seem desperate to stay in the weight they're at, to try and give themselves a bit of an advantage. The kids want the medals and the parents tend to support them you know.* *- Well I'd say certainly with cadets it's the parents. With juniors the older they get they rely more on the coaches, I think, you know, with coaches guiding them, the coaches can guide the cadets on which weight division to go for and stuff like that. But as for telling them what to, or you could advise them on what to eat but because the parents are with them 24/7 the parents should be aware of if they're eating correctly, that they're eating enough and what's happening with the weight, do you know what I mean?* *- I found out his dad had them on laxatives, a fucking 14 year old boy. You know we put a stop to it straight away like.*
		Parent 2	*- Yeah parents for cadets, this is why it needs to be public, this information, on how to lose weight at certain ages because obviously for under 18s it will be the parents as they're the main influence. Every parent thinks they're the best coach in the world and they're not, that's the simple answer to that.* *- When they get up to senior level, they go to their coaches, the first coach always has some sort of influence.* *- I mean the national team selection policy is always going to have a massive part to play. You might be a good athlete but if you don't fit their criteria for a certain weight then you're fucked.*
PARENT (non Taekwondo)		**Parent 3**	*- I think what you find then is that there is a level of parent influence and I think they're influenced by, other athletes who are tall players and win matches.* *- I do believe that certain coaches who influence their policy to, as you can see some coaches they go away or they go to competition and they're all in sweat boxes, they're all sat round and this is not seniors, this is juniors and they're all desperate for weigh in to open.* *- I think it becomes a peer group thing then within the clubs.* *- I always say the key influence is the national team. They send the message out, if you look at their preferred style of player, it's a thin, lean, bodied player and really tall.*

PARENT (non Taekwondo)	**FEMALE**	**Parent 4**	*- If the information was there for everybody, parents included to help them understand what they should and what they shouldn't be doing then it wouldn't be such a big deal for the kids. I mean I'm not an expert am I.* *-At the end of the day parents have a say in what they think, but ultimately it is down to that athlete. I mean, if, say for instance, my daughter is fighting a 53 and say someone like a coach said to her 'well we want you to get to 49' she has to think whether she can physically get to that without damaging herself because there's nothing there to lose.* *- I think with some coaches, say you've got what, seven seniors and say like four of them are all in the same weight group, you're not wanting those to fight against each other are you?* *- I know, like, some coaches say to them 'look, we need to, you need to drop them down' so I do think coaches sort of force the issue sometimes.*
		Parent 5	*- If my son wanted to fight at a particular weight and then obviously now he's an adult it's his decision and in discussion with coaches at the national team.* *- It's difficult because nobody will tell you that they're forcing their child to lose weight will they so I think with a lot of kids it is parents and coaches.* *-I think there's a lot of pressure on some kids from parents and coaches to make weight because again, if you're at the top of that weight you're obviously, well you're usually in a better position because you normally are taller.* *- The national team and selection policies do have an influence. When you get selected to represent your country you want to do it don't you? You don't want to go 'look, I can't make this weight' So it's very difficult for them to resist doing it either rightly or wrongly.*

APPENDIX 4

Taekwondo specific 15 minute RAMP warm-up protocol

RAISE

EXERCISE	MOVEMENT	TIME (seconds)	TOTAL TIME (minutes)
Jog forward/backward	*Anterior/Posterior*	30	**0.30**
Side star - jumps	*Lateral*	30	**1.00**
Floor sweeps	*Anterior/Posterior*	30	**1.30**
Laterals	*Lateral*	30	**2.00**
Kick-outs forward/backward	*Anterior/Posterior*	30	**2.30**
Carioca	*Lateral*	30	**3.00**
Knee raises	*Anterior/Posterior*	30	**3.30**
Side Squats	*Lateral*	30	**4.00**
Lunges	*Anterior/Posterior*	30	**4.30**
Jog forward/backward	*Anterior/Posterior*	30	**5.00**

ACTIVATE & MOBILISE

EXERCISE (ROM)	MUSCLES (Stretched)	TIME (seconds)	TOTAL TIME (minutes)
Rising stomach *Anterior core stabilisers*	• *Rectus abdominis* • *Internal/external intercostals* • *Internal obliques* • *Iliacus* • *Psoas major/minor* • *Transverse abdominis*	15	**0.15**
Rotating stomach (right/left) *Anterior core stabilisers*	• *Rectus abdominis* • *Internal/external intercostals* • *Internal obliques* • *Iliacus* • *Psoas major/minor Transverse abdominis* • *Quadratus lumborum*	15	**0.30**
Crouching heel back calf (left) *Inferior posterior leg stabilisers*	• *Plantaris* • *Tibialis posterior* • *Flexor digitorum longus* • *Flexor hallucis longus* • *Peroneus longus/brevis*	15	**0.45**

	• *Gastrocnemius* • *Soleus*		
Crouching heel back calf (right) *Inferior posterior leg stabilisers*	• *Plantaris* • *Tibialis posterior* • *Flexor digitorum longus* • *Flexor hallucis longus* • *Peroneus longus/brevis* • *Gastrocnemius* • *Soleus*	15	**1.00**
Sitting bent *Posterior core stabilisers*	• *Multifidis* • *Longissimus thoracis/cervicis* • *Iliocostalis lumborum/thoracis/ cervisis* • *Spinalis thoracis*	30	**1.30**
Lying knee to chest (left) *Superior posterior leg stabilisers*	• *Gluteus maximus* • *Iliocostalis lumborum*	15	**1.45**
Cross over knee pull (left) *Lateral leg abductors*	• *Gluteus minimus/medius* • *Tensor Faciae Latae* • *Piriformis*	15	**2.00**
Lying knee to chest (right) *Superior posterior leg stabilisers*	• *Gluteus maximus* • *Iliocostalis lumborum*	15	**2.15**
Cross over knee pull (right) *Lateral leg abductors*	• *Gluteus minimus/medius* • *Tensor Faciae Latae* • *Piriformis*	15	**2.30**
Sitting knee to chest (left) *Superior posterior leg stabilisers*	• *Gluteus maximus* • *Semimembranosus* • *Biceps femoris* • *Semitendinosus*	15	**2.45**
Sitting knee to chest (right) *Superior posterior leg stabilisers*	• *Gluteus maximus* • *Semimembranosus* • *Biceps femoris (Long/short heads)* • *Semitendinosus*	15	**3.00**
Lying quadriceps (left) *Superior anterior leg stabilisers*	• *Vastus medialis* • *Vastus Intermedius* • *Rectus femoris* • *Vastus Lateralis*	15	**3.15**
Lying quadriceps	• *Vastus medialis*	15	**3.30**

(right) *Superior anterior leg stabilisers*	• *Vastus Intermedius* • *Rectus femoris* • *Vastus Lateralis*		
Standing toe point (left) *Superior posterior leg stabilisers*	• *Semimembranosus* • *Biceps femoris (Long/Short heads)* • *Semitendinosus*	15	**3.45**
Standing toe point (right) *Superior posterior leg stabilisers*	• *Semimembranosus* • *Biceps femoris (Long/Short heads)* • *Semitendinosus*	15	**4.00**
Hip flexor (left) *Deep anterior stabilisers*	• *Iliacus* • *Psoas major/minor*	15	**4.15**
Half scissor (left) *Medial leg adductors*	• *Adductor longus/brevis/magnus* • *Gracilis* • *Pectineus*	15	**4.30**
Hip flexor (right) *Deep anterior stabilisers*	• *Iliacus* • *Psoas major/minor*	15	**4.45**
Half scissor (right) *Medial leg adductors*	• *Adductor longus/brevis/magnus* • *Gracilis* • *Pectineus*	15	**5.00**

POTENTIATE

EXERICISE	**TIME (seconds)**	**TOTAL TIME (minutes)**
Back leg turning kick *(dollyo chagi)* Front leg turning/fast kick *(barumba chagi)* Counter back leg turning kick *(nadabong dollyo chagi)* **FREE REACTION**	**120**	**2.00**
Combination **1**	**60**	**3.00**
Combination **2**	**60**	**4.00**
Combination **3**	**60**	**5.00**

COMBINATION ORDER

COMBINATION 1

1. Front leg turning/fast kick
   (barumba chagi)
2. Back leg turning kick
   (*dollyo chagi)*
3. Counter back leg turning kick
   (nadabong dollyo chagi)

COMBINATION 2

1. Back leg turning kick
   (dollyo chagi)
2. Counter back leg turning kick
   (nadabong dollyo chagi)
3. Front leg turning/fast kick
   (barumba chagi)

COMBINATION 3

1. Counter back leg turning kick
   (nadabong dollyo chagi)
2. Front leg turning/fast kick
   (barumba chagi)
3. Back leg turning kick
   (dollyo chagi)