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STATEMENT OF ORIGINALITY

This thesis describes original research conducted by the author at the Australian Institute of Sport while in the School of Health and Sports Sciences at The University of the Sunshine Coast from April 2014 to March 2017.

A number of individuals have contributed substantially to research presented in this thesis. Their contributions follow…

- Assoc Prof Gary Slater  Research design, data analysis
- Prof Louise Burke  Research design, data collection and analysis
- Dr Greg Cox  Research design, data analysis
- Dr Clare Humberstone  Research design, data collection
- Dr David Martin  Research design

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Gary Slater
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Throughout my PhD years I have been extremely fortunate to be based at the Australian Institute of Sport, and to feel at home within three world class departments; the Combat Centre, the Physiology Department, and Sports Nutrition.

The AIS Combat Centre represents my biggest passion, combat sports. If it was not for the foresight and management of Dr Clare Humberstone and Dr David Martin, I certainly would not be in the position I am now. David is certainly one of kind, and the limited opportunity I had to work with him and benefit from his eccentric passion and limitless energy will no doubt benefit me for the rest of my life. Clare is a fantastic manager, professional and friend. David left big shoes to fill when departing the Combat Centre and Clare not only did the job which was required, but did it her way. Clare provided a structured, targeted approach to assist Australian Combat Sports in their Olympic efforts, whilst concurrently providing a supportive environment for students and sports science as a whole. I know I speak for all the
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PUBLICATIONS

At the time of submitting this thesis, the following papers are ‘in press’ or have been submitted for publication and are in review:


ABSTRACT

Unarmed Olympic combat sports include the striking sports of boxing and taekwondo and the grappling sports of judo and wrestling. All of these sports separate competitors into weight divisions, attempting to reduce physical differences and create ‘an even playing field’. It is common for these athletes (and those in other weight category sports) to undertake both chronic and rapid weight loss (RWL) prior to competition in an attempt to obtain a competitive edge over smaller opponents. Recognising this, reviews and guidelines have been established to assist with optimising chronic body mass (BM) management in combat sport athletes. However no consolidated guidelines for RWL exist, despite the vast majority of combat sport athletes engaging in these practices. Thus the overarching aim of this body of work was to complement existing chronic BM guidance by developing pragmatic guidelines and recommendations regarding acute BM manipulation to assist Australian Olympic combat sport athletes.

An initial literature review was conducted to; a) identify gaps in the existing literature which could be investigated to better inform acute weight management guidelines, b) investigate the underlying physiology as well as the health and performance effects associated with different methods of RWL, and c) devise practical recommendations to guide the achievement of specified BM targets while minimising performance decrements and health implications. Key findings identified within the review of literature included the:

- Lack of directly comparable data regarding athlete BM management practises across Olympic combat sports
• Absence of investigations in judo and boxing examining the link between RWL and competitive success (currently only wrestling and taekwondo had been investigated)

• Paucity of elite combat sport athlete body composition data collected utilising validated measurement techniques

• Existence of novel RWL techniques anecdotally used by combat sport athletes but without scientific scrutiny

• Lack of context specific recommendations guiding the post weigh-in recovery period.

In the first study (study one) weight loss practices among Australian Olympic combat sport athletes were investigated. High calibre competitors in wrestling, boxing, judo and taekwondo (n=260) at Australian competitions were surveyed using a validated tool which provided quantification of how extreme an athlete’s weight loss practices are; the rapid weight loss score (RWLS). Additional qualitative and quantitative survey data were also collected. It was found that neither sport, sex or weight division had an effect on RWLS however a significant effect of athlete calibre (determined via athletes’ historic competitive success) was detected \[ F (2,215) = 4.953, \text{MSE} = 4.757, \ p = 0.00792 \], with higher calibre athletes reporting higher RWLS’. Differences between sports were also evident, including most weight ever lost in order to compete \[ H = 19.92, \ p = 0.0002 \], age at which weight cutting began \(H = 16.34, \ p = 0.001\) and selected methods/patterns of RWL \(p < 0.001\). Of note; wrestlers tended to favour rapid over chronic weight loss and utilised passive sweating techniques more than other athletes. Weight cycling between competitions was common among all sports as were influences on athlete’s behaviours, with coaches and other athletes providing the greatest influence. The results from study one suggest many similarities.
in weight loss practices and experiences exist between combat sports, however specific differences are evident. Furthermore, novel RWL techniques are emerging, particularly ‘water loading’. Consequently, nuanced, context and culturally sensitive guidelines, specific to each combat sport should be devised to assist fighters’ in optimising performance while minimising health implications.

Study two examined the relationship between RWL and competitive success in real life judo competition, following prior exploration of this issue amongst wrestling and taekwondo athletes. Eighty-six (36♀/50♂) senior judoka volunteered for this observational study at an international judo competition. Subjects were weighed at the official weigh-in and again one hour before their first competition fight (15-20 hours later), with weight regain used as an index of the degree of RWL undertaken. Regain in BM after weigh-in was compared between medallists and non-medallists, winners and losers of each fight, males and females and weight divisions. Heavyweights were excluded from analysis. It was revealed that BM re-gain was significantly higher in medallists than non-medallists for males and females combined (1.4±0.4% BM; p=0.0026; ES= 0.69; CI95% [0.05, 2.34]) and for males alone (1.5±0.6% BM; p=0.017; ES= 0.74; CI95% [0.02, 2.64]), but not for females (1.2±0.7% BM; p=0.096; ES=0.58; CI95% [-0.02, 2.31]). Differences in BM re-gain after weigh-in between winners and losers were significant across all fights (0.9±0.3% BM; p=0.0021; ES= 0.43; CI95% [0.31, 1.41]) but not for first round fights (0.8±0.5% BM; p=0.1386, ES=0.38; CI95% [-0.26, 1.86]). In summary, overall winners showed a greater re-gain in BM post weigh-in than losers. This may reflect a greater magnitude of BM loss needed to achieve weigh-in targets and/or that larger athletes possess a competitive advantage.
Study three aimed to build upon the findings from study two, investigating the relationship between RWL and competitive success in boxers. Additionally, we sought to gain insight into boxers post weigh-in nutrition practices, given the implications of this on BM regain and performance. One hundred (30♀/70♂) elite boxers participating in the Australian National Championships were weighed at the official weigh-in and an hour before each competition bout (~4-10 hours later, depending on competition schedule). Re-gain in BM after weigh-in was compared between finalists and non-finalists, winners and losers of each fight, males and females and weight divisions. Boxers were surveyed on their pre and post weigh-in nutrition practices. Analysis of the data revealed no differences in BM re-gain between finalists and non-finalists, winners and losers of individual bouts, or between preliminary or final bouts. BM re-gain was significantly greater (0.37% BM, p < 0.001; ES=0.25) prior to an afternoon bout compared to a morning bout. Results from the survey data indicate boxers favour water over electrolyte drinks and often consume fibre rich foods post weigh-in. Thus we concluded that although boxers engage in RWL practices before the official competition weigh-in, this does not appear to affect competition outcomes, at least when weight re-gain between weigh-in and competition is used as a proxy for the magnitude of RWL. Furthermore, while boxers recognise the importance of recovering after weigh-in, current athlete practices are not aligned with best practice guidance.

Study four sought to develop a descriptive database of physique traits amongst Olympic combat sport athletes, compare variables relative to weight division and examine differences within and between sports. Olympic combat sport athletes (56♂/38♀) had BM, stretch stature and dual-energy X-ray absorptiometry derived body composition assessed within 7-21 days of competition. Most athletes were
heavier than their weight division. Sport had an effect (p<0.05) on several physique traits, including lean mass, lean mass distribution, stretch stature and BMI. Of note, taekwondo athletes tended to possess lower BMI and relative fat and lean mass. BM was positively correlated (r>0.6, P value) with fat free mass, fat mass and body fat percentage. However this was not predictive of the ratio between total mass and weight division, perhaps suggesting athletes plan for a relative acute weight loss prior to weigh-in. The Olympic combat sports differ in competitive format and physiological requirements, which is partly reflected in athletes’ physique traits. Reference ranges for lean and fat mass across a range of BM are presented (Figure 6.2). The findings from this study suggest that athletes in lighter weight divisions often are required to utilise RWL in order to make weight, whereas heavier athletes have greater potential to utilise chronic interventions (e.g. reduce fat mass) to make weight. These data may assist athletes and coaches to better identify realistic and achievable physique traits.

Following the identification of athletes utilising ‘water loading’ as a novel method to facilitate RWL (Study One), study five sought to clinically evaluate the effectiveness and safety of this practice. Reports suggest water loading (the consumption of large volumes of fluid for several days, prior to withholding intake) increases body water losses during fluid restriction, relative to no water loading prior to restriction. To investigate; 21 male combat sport athletes were separated into a control (CON, n=10) and water loading (WL, n=11) group. Subjects were fed a standardised isoenergetic diet based on fat free mass (assessed via DXA scan) controlling for macronutrient, sodium and fibre content for 6 days. On days 1-3, fluid intake was 40ml kg⁻¹ for CON and 100ml kg⁻¹ for WL. Day 4 fluid intake was 15ml kg⁻¹ for both CON and WL. On day 5 no fluid was consumed until midday with both groups thereafter following the
same rehydration protocol until day 6. Urine sodium concentration, specific gravity (USG) and volume were recorded alongside training sweat losses throughout. Renal hormones (vasopressin, renin, and aldosterone), blood urea and electrolytes (U+Es), plus BM were measured each morning (fasted) and evening following 30 min supine rest. Physical performance was assessed pre and post intervention. Following fluid restriction, BM loss between day 5 and 6 in WL was double that of the CON; significant differences with large effect sizes were found in fluid input/output ratio (39.11%, p < 0.01, ES=1.2) and BM loss (0.6%BM, p=0.02, ES=0.82) revealing the effectiveness of WL in increasing fluid output. No differences in performance measures existed. Time had a significant effect on USG, all U+Es and renal hormones (p < 0.05). Throughout the intervention, WL resulted in significant changes (i.e. an interaction between time and intervention was found) in blood sodium, potassium, chloride, urea, creatinine, and vasopressin concentrations, plus USG (p < 0.05) but not on other hormones or electrolytes. No mean U+Es differed from reference ranges or approached critical values. In conclusion, water loading appears to be a safe and effective method of RWL under the conditions utilised in this study. Changes in vasopressin may in part underlie the mechanism facilitating this response.

The work presented thus far has focused on RWL prior to weigh-in utilised by Olympic combat sport athletes. Alongside pre-weigh in RWL, key factors to be considered when optimising acute BM management practices include the requirements of the individual combat sport, the specific weigh-in regulations and crucially the time available for recovery between weigh-in and competition. In order to consolidate existing research with the findings derived from the present body of work, we present a review summarising optimal post weigh-in recovery strategies, as well as further individualising other aspects of RWL for the different Olympic combat
sports. Optimal post weigh-in nutrition will depend on the methods used to achieve RWL pre weigh-in, and suitable magnitudes of RWL and optimised body composition will depend on the weigh-in regulations and physiological requirements of individual sports.

In conclusion, the studies presented in the thesis extend previous findings on; athletes’ BM management practices, the link between RWL and competitive success, the overlap between chronic and acute BM management, what may constitute an ideal weight division and the efficacy and safety of a popular and novel method of RWL. The survey data indicate that although Olympic combat sport athletes share many similarities in BM management practices, several differences exist which should be considered when delivering context specific advice to athletes and coaches. When placed in context with earlier work, our findings suggest that RWL (and BM regain post weigh-in) provides a competitive benefit in the grappling sports of judo and wrestling, but not in the striking sports of boxing or taekwondo, presumably by affording larger athletes an opportunity to compete against smaller opponents. This information is valuable in determining the ‘cost to benefit’ of RWL and in devising sports specific recommendations. The ‘reference ranges’ we report for chronic BM management can be used as targets for aspiring elite athletes and revealed that RWL is indeed necessary for the majority of lighter athletes to make weight for self-determined weight categories (as body fat is already low), whereas heavier athletes can potentially make weight through body fat losses. The process of water loading appears safe (under the conditions utilised in the trial) and was effective in promoting increased fluid losses and thus greater RWL. Further, we propose a plausible mechanism explaining the effectiveness of water loading which may assist future
research in further refining this technique. In addition to the original research presented, two published reviews outline evidenced based RWL, post weigh-in recovery and sports specific BM management guidelines. In summary, this thesis has contributed substantially to the RWL research literature and moving forward will assist in the pragmatic advice offered to athletes and coaches by sports science support staff working with Olympic combat sports but with potential broader application to other athletes in weight category sports.
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Chapter 1
BACKGROUND AND THESIS OVERVIEW
Combat sports and martial arts

Often grouped together, combat sports and martial arts share obvious similarities and cross overs in practice, traditions and training methodologies; however distinctions between the two can be made. A martial art is typically thought of as a series or system of physical and mental practices and traditions, rooted in or symbolising actual combat and can be practiced for a variety of reasons (1). Self-defence, law enforcement and military application alongside spiritual, mental, psychological and emotional development may be the goals of one practising martial arts, or the purpose may be the preservation of culture or even for entertainment purposes. Many nations and ethnic groups have developed and maintained their own unique forms and there are literally hundreds of martial arts practiced throughout the world, with new styles being developed each year (1). Although often associated with fighting arts originating in Asia, various forms of martial arts and combat systems have arisen independently throughout the world, including Europe and Africa (1, 2). In fact wrestling is often noted as one of the oldest sports and is one of the original inclusions in the ancient Olympic Games (3).

Combat sports, as opposed to martial arts, are the practices of fighting styles in a competitive environment under a specific set of rules and regulations. In a broad sense, combat sports can be divided into striking sports and grappling sports. Striking sports include those which primarily involve the use of the arms and legs to ‘throw strikes’ (kicks, punches, knees, elbows etc.), in an attempt to inflict physical damage or score points, usually with the goal of knocking down or knocking out an opponent. Grappling sports include those sports which limit striking and instead rely on clinching, holding, grabbing, throwing, pinning or otherwise manipulating an opponent through the use of leverage and body positioning, usually with the goal of throwing, tripping or downing an otherwise standing opponent, controlling/pinning a downed opponent or submitting an opponent (forcing the opponent to give up via the use of a
choke hold or joint manipulation, threatening serious injury). Although these two broad classifications encompass most of the combat sports, forms which combine both striking and grappling exist (such as the sport of mixed martial arts (MMA)) as do forms which include the use of weapons and those involving more than two competitors within a match.

Much like martial arts themselves, there are increasing varieties of combat sports practiced throughout the world from recreational to the elite level including the Olympic Games. Combat sports at the Olympic Games include the grappling sports of judo and two varieties of wrestling; freestyle and grecco-roman, plus the striking sports of boxing and taekwondo. At the upcoming 2020 summer Olympics games in Tokyo, Japan, karate will also be included for the first time on the Olympic Program. Lastly, in addition to the unarmed combat sports, the sport of fencing, whereby competitors attempt to score points by making contact with an opponent using a sword is also contested at the Olympic games and may be included under the umbrella ‘Olympic combat sports’. However, fencing stands out from the other combat sports on the Olympic schedule as it is the only one of the sports utilising a weapon, does not include weight divisions, and requires a considerably different set of physiological attributes and skills relative to the unarmed combat sports (4-8).

In consideration of conducting a thorough yet targeted analysis of pertinent literature, conducting applied research and providing pragmatic findings, the body of work comprised within this thesis will not investigate fencing, and instead focus on the unarmed Olympic combat sports. Furthermore, as the vast majority of this work was completed prior to the announcement of karate’s inclusion at the Olympic Games, the focus of this work will not comprise karate either; however passing comments are included where appropriate, including learnings with application to Karate.
Weight divisions and combat sports

In the majority of combat sports and all of the unarmed Olympic combat sports, competitors compete in weight divisions (otherwise known as weight classes or weight categories), separating athletes according to body mass (BM). The idea behind the concept of weight divisions is to create an ‘even playing field’ in which one competitor does not possess a significant size advantage over another. Although weight divisions are determined by BM, this does not completely eliminate the physique trait discrepancies between competitors, as athletes may still attempt to maximise particular physical qualities thought to be advantageous in competition. For example, in sports where range and distance management are important, maximising stature (and thus presumably limb length and ‘reach’) at a given BM at the expense of muscle mass (and strength and power) may be an acceptable trade off (9-12). Whereas the opposite may be true in sports where strength and power are perceived to be more important. Given this reality, it makes sense and is common place for athletes to attempt to reduce ‘non-functional’ mass (e.g. body fat), in order to carry as much functional mass as possible at a given weight (13), although body composition assessments of combat sport athletes using precise measurements techniques are rare (14).

The ‘weigh-in’

Adding even further nuance to athletes’ BM management efforts, is the fact that competitors are not required to maintain their selected weight division mass at the actual time of competition, rather they have their BM verified at some time prior to competition at an ‘official weigh-in’. This process of successfully attaining ‘competition weight’ at the time of the official weigh-in is colloquially known as ‘making weight’. In the Olympic combat sports, the official weigh-in may be conducted as few as three hours prior to the first competitions of the day (as is the case in boxing) or the day before competition, equating to
~16-24 hours between weigh-in and competition. Judo, taekwondo and wrestling athletes attend only one official weigh-in and complete all of their competitive efforts in one day, the day following weigh-in. Amongst boxers; athletes who are successful in progressing through the competition draw compete in successive bouts over multiple days, and are required to weigh-in on the morning of each competition day. This time interval between the official weigh-in and start of competition may be seen as an attempt from organisers to mitigate the physiological implications associated with commonly used ‘weight making’ strategies. However this may be one of the key factors influencing athletes’ weight loss behaviour, affording competitors the opportunity to restore physiological attributes at the time of competition which may be compromised whilst making weight. In effect, aside from chronically reducing BM and attempting to achieve low levels of body fat, athletes commonly acutely reduce BM in the hours and days prior to weigh-in via food and fluid restriction and activities aimed at reducing body water, before enacting recovery strategies (ingestion of food and fluids) post weigh-in. Thus at least partially restoring physiological function and presenting to competition significantly heavier than at the official weigh-in (15-18).

**Acute weight loss**
Acute weight loss is practiced by the majority of combat sport athletes and indeed athletes within other weight category sports (13, 19). Various terms may be used to describe the process of acute weight loss, such as rapid weight loss (RWL), making weight, weight making, weight cutting, cutting weight and cutting; however essentially they are referring to BM loss in a short period of time which is predominantly fat free mass (i.e. water, gastrointestinal tract contents, plus muscle and liver glycogen). For the purposes of this thesis, the terms acute weight loss, rapid weight loss, cutting weight and weight making will
all be used to refer to this process and may be alternated throughout the subsequent chapters (as the chapters represent different manuscripts published in peer-reviewed scientific journals, each using its own terms).

The magnitude of rapid weight loss before weigh-in is commonly reported at around 5% of BM across all combat sport athletes (13, 15, 20, 21); however differences exist in the time spans over which the weight is lost and how frequently this occurs. Extremes in acute weight loss are also evident, with some athletes reporting acute losses greater than 10% BM (22).

Negative performance and health consequences of such severe weight loss have been well documented not only within combat sport athletes but across varying athletic populations (16, 23-27). In the extreme, severe weight making practices have resulted in deaths, as was the case in November 1997 when three America wrestlers died following food and fluid restriction in conjunction with the use of vapour impermeable suits while exercising in a hot and humid environment (28).

Responding to such events, organisers instituted rule changes in the national competition, in an effort to curtail extreme weight making practices in these wrestlers (29). Further, position statements from the American College of Sports Medicine (30), The Association of Ringside Physicians (31) and the National Athletic Trainers Association (32) warn against extreme practices and recommend further rule changes across sports to discourage large magnitudes of acute weight loss and specific methods of weight loss. Some have even called for the complete abolition of acute weight loss, describing it as cheating and likening it to doping (33), in that it provides an unfair advantage and is against the spirit of sport among other factors. Rule changes regarding altered weigh-in time frames relative to competition, identified minimum competition weight requirements (based on body composition assessment) and testing of hydration status appear effective in decreasing extreme weight loss practices (29). However when these same athletes (who reduced their extreme practices
following rule changes) compete in competitions which do not implement such rules, extreme practices resume (34). Thus despite the well documented negative effects, plus medical and health authorities efforts to discourage the practice, athletes continue to follow longstanding patterns of weight cutting in order to make weight.

**Continued utilisation of acute weight loss**

Perhaps one of the greatest factors reinforcing weight cutting practices is the opportunity for recovery post weigh-in. Following acute weight loss, performance in activities demanding high contributions of aerobic and anaerobic metabolism are typically compromised (35) as are (albeit to a lesser degree) activities demanding high power output and absolute strength (36, 37). However much of these physiological disturbances may be reversible following nutritional recovery post weigh-in. Indeed two and a half days of ‘sweating’ plus food and fluid restriction, resulted in no change in anaerobic capacity determined via a 1 min Wingate test, following 5 h recovery (38). In addition to anaerobic performance, similar findings have been found regarding transient changes to psychological, cognitive, and sport specific parameters relative to combat sports (39-43). On top of the fact that performance decrements may be ameliorated post weigh-in, success in combat sports is not dependant on absolute performance, rather performance relative to an opponent; thus athletes appear to make ‘estimates’ of the net benefit of engaging in acute weight loss, considering the negative effects of acute weight loss, the potential for post weigh-in recovery and the advantage offered by competing in a lighter weight division against smaller opponents.

Aside from the recognition that the time available post weigh-in provides opportunity to restore physiological function, at least in part; combat sport athletes report deriving a ‘sporting identity’, a sense of focus and commitment and the feeling that they are ‘a real athlete’ when engaging in the weight making process (44, 45). Although many believe that
undertaking acute weight loss is a key component and an important aspect of their sport (44) increasing chances of success, studies examining this relationship report mixed findings and have not been conducted in all Olympic combat sports (46-48). Thus the identification of circumstances in which strategically managed and moderated acute weight loss may aid competitive success is needed for each of the Olympic combat sports.

**Pragmatic support for athletes**

It is apparent that regardless of health risks, decrements in absolute performance and warnings from medical and sporting authorities, plus changes to the regulation of specific sports, athletes continue to engage in both chronic and acute weight loss in order to compete in weight divisions below their ‘natural’ or day-to-day training weight. Recognising this, researchers have devised pragmatic guidelines aimed at attenuating some of the risks involved in these practices. To date, there are several review articles summarising the literature and providing dietary intake targets for a variety of situations and sports including (but not limited to) generalised realistic and safe chronic BM management and fat loss practices (32), chronic BM management, fat loss and daily training support in combat sport athletes with brief mention of acute weight loss (49), and sport specific commentary on chronic and acute BM loss and recovery in light weight rowing (50). What is lacking are detailed, sport specific, pragmatic guidelines aimed at assisting combat sport athletes, coaches and support staff in optimising acute BM management around weigh-in and subsequent recovery pre-competition.

**Thesis aim and structure**

The aim of this body of work is to understand acute BM management, its effects on competitive performance and the associated physiological implications. Further, we aim to
develop pragmatic guidelines which will identify optimised methods of acute weight loss in Olympic combat sports, with due consideration to the health and performance implications of such approaches. Additionally we seek to investigate pertinent research, identify gaps in the current literature and examine novel areas which will further enhance recommendations to athletes, coaches and support staff. What follows are a series of publications currently accepted or in review which follow a sequence of investigation leading to a consolidation of thoughts and ideas further enhancing pragmatic advice to this cohort.

First, an initial published literature review examining the underlying physiology of acute weight loss is presented, which identifies evidenced based optimised methods of acute weight loss, highlighting gaps in the current literature. Following this initial review is a series of studies investigating weight loss practices, the relationship between acute weight loss and success, the ‘overlap’ between chronic and acute BM management, and the implications of a novel method of acute weight loss popular among combat sport athletes. Following the original research presented, sport specific commentary on acute weight loss and detailed post weigh-in recovery is offered in the form of guidelines in another published review paper.

Lastly, a concluding chapter summarises the work conducted and synthesizes the knowledge gained throughout the current thesis into further applied recommendations and suggestions for future scientific inquiry.
Chapter 2
REVIEW OF LITERATURE

Published as invited brief review in

International Journal of Sport Physiology and Performance:

“Acute weight loss strategies for combat sports and applications to Olympic success”

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3 Australian Catholic University, Melbourne, Victoria, Australia
Abstract / summary

It is common for athletes in weight category sports to try to gain a theoretical advantage by competing in weight divisions that are lower than their day-to-day body mass (BM). Weight loss is achieved not only through chronic strategies (body fat losses) but also through acute manipulations prior to weigh-in (“making weight”). Both have performance implications. In this review we focus on Olympic combat sports, noting that the varied nature of regulations surrounding the weigh-in procedures, weight requirements and recovery opportunities among these sports provide opportunity for a wider discussion of factors that can be applied to other weight category sports. We summarise previous literature that has examined the performance effects of “weight making” practices before investigating the physiological nature of these BM losses. Practical recommendations in the form of a decision tree are provided to guide the achievement of acute BM loss while minimising performance decrements.
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Methods, prevalence and magnitude of acute weight loss
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Respiration and water loss
Urination and water loss
Sweating and water loss
Sodium intake and water loss
Glycogen, bound water and acute weight loss
Gut contents and acute weight loss

Section 3.
Conclusions and practical applications
Section 1.

Introduction
In a number of sports, athletes compete in defined weight divisions designed to match competitors according to body mass (BM) as a proxy for body size. This regulation creates a number of unique challenges and practices related to the manipulation of BM around competition that must be integrated into sports nutrition goals and performance considerations. It is beyond the scope of this review to provide an in-depth commentary on the specific issues in all such sports; however, weight category sports on the Olympic Games Program are of interest. These sports, which feature only at the Summer Games, include rowing, weight lifting and the majority of combat sports (i.e. boxing, taekwondo, judo, freestyle wrestling and Greco-Roman wrestling) (51). Indeed at the 2016 Rio Olympic Games, combat sports will make up 53 of the 306 available gold medals; consequently empirically based guidelines focusing on this population will benefit a large cohort of athletes and support staff (51). The aim of this paper, therefore, is to investigate the specific features of weight-making in Olympic combat sports. We note that the varied nature of regulations surrounding the weigh-in procedures, weight requirements and recovery opportunities among these sports will provide opportunity for a wide discussion of factors that can be applied to other weight category sports.

Weight categories and weight loss
Weight divisions have been established to create ‘an even playing field’ in which competitors are matched for physical size (BM). Official ‘weigh-ins’ are held prior to a competitive event, and also on subsequent days in multi day competitions, to certify that athletes have met the requirements of their intended competition division (known as ‘making weight’). The
duration of the period between weigh-in and competition varies according to the rules of sport, and dictates the opportunity to undertake strategies to recover from acute weight loss (AWL) practices often implemented to achieve the BM target. In the case of boxing, which instigates a morning weigh-in, recovery time can range from three hours for athletes who fight in the first bouts of the day to twelve hours for competitors in the later bouts. In judo, wrestling and taekwondo, weigh-ins held the evening prior to competition may provide an interval of around 16 hours. These time frames contrast with conditions in the other Olympic weight category sports (lightweight rowing and weightlifting) in which there is a fixed period of two hours between weigh-in and competition. Despite the original intention of matching opponents by size, athletes recognise the opportunities provided by the weigh-in format: it is common for fighters to reduce BM using both chronic and acute techniques to qualify for a weight division that is lighter than their ‘natural’ or day-to-day BM, thus gaining a theoretical advantage in size/strength/leverage over smaller opponents. Furthermore, in the Olympic combat sports, where the intervals between the lighter weight divisions are smaller in absolute terms (Table 2.1), there is a potential ‘temptation’ for smaller athletes to engage in larger relative AWL. Indeed, there is evidence that those competing in the lighter weight divisions achieve greater relative weight losses than those in heavier weight divisions (46, 52), indicating that many athletes intend to compete in the lightest weight division possible.
Table 2.1 Olympic combat sports weight divisions (kg)

<table>
<thead>
<tr>
<th>Freestyle Wrestling</th>
<th>Greco-Roman Wrestling</th>
<th>Judo</th>
<th>Boxing</th>
<th>Taekwondo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men’s</td>
<td>Women’s</td>
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<td>&lt;48</td>
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<td>46-49</td>
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<td>&gt;78</td>
<td>75-81</td>
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</tbody>
</table>

Professionals who work with these athletes should gain an understanding of current BM manipulation practices, the physiological attributes and consequences of chronic and AWL, as well as the weigh-in procedures and competition format of Olympic combat sports (Table 2.2).
<table>
<thead>
<tr>
<th>Sport</th>
<th>Weigh-in procedures</th>
<th>Competition format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle Wrestling</td>
<td>Once, evening before competition</td>
<td>All contests for one weight division in single day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Best of 3 x 2 min rounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winner by immobilisation of opponent on back (pin) or by judges decision via points once time has elapsed</td>
</tr>
<tr>
<td>Greco-Roman Wrestling</td>
<td>Once, evening before competition</td>
<td>All contests for one weight division in single day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Best of 3 x 2 min rounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winner by immobilisation of opponent on back (pin) or by judges decision via points once time has elapsed</td>
</tr>
<tr>
<td>Judo</td>
<td>Once, evening before competition</td>
<td>All contests for one weight division in single day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 x 5 min match</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winner by ippon (throwing opponent on back with strength and speed, forcing opponent to submit with arm lock or stranglehold, immobilisation of opponent on back) or by judges decision via points once time has elapsed</td>
</tr>
<tr>
<td>Boxing</td>
<td>Morning on the first day of competition and morning of every contest day</td>
<td>Successive contests on separate days</td>
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<td>No less than 3 hours between weigh-in and contest</td>
<td>2 x 3 min rounds (men)</td>
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<td></td>
<td></td>
<td>4 x 2 min rounds (women)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winner by knockout, technical knockout, referees stoppage or by judges decision via points at end of bout</td>
</tr>
<tr>
<td>Taekwondo</td>
<td>Once, evening before competition</td>
<td>All contests for one weight division in single day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 x 2 min rounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electronic sensor scoring system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winner by knockout, reaching 12 point difference at completion of second round or via superior score at end of bout</td>
</tr>
</tbody>
</table>
Thorough reviews of the research of weight loss practices and the effects on health and performance outcomes for athletes have been published in the past, examining chronic and acute strategies in the wider athlete population (23) and the specific issue of AWL practices in combat sport athletes (16). It is clear is that both chronic and AWL practices are associated with negative outcomes. In terms of chronic practices, the International Olympic Committee recently released a consensus statement detailing the issue of chronic energy deficits in athletes attempting to chronically manage BM and the potential detrimental effects on; lean mass maintenance, immune function, bone health, metabolic rate and hormonal processes (53). Although this statement is applicable to a wide variety of athletes who manipulate their BM and composition to improve power to weight ratios, the unique feature of combat sports (and other weight category sports) is the superimposition of the AWL phase around competition.

Acute weight loss or ‘weight cutting/making’ is an ingrained practice in combat sports. Indeed, one study has reported that its prevalence is twice as high as the use of gradual weight loss strategies (20). Combat athletes report that coaches and team mates, as well as their personal desire to win, are the biggest influences on their decisions regarding weight loss efforts (54). From their perspective, weight making provides more than a physical advantage over an opponent. Qualitative research indicates that athletes derive a sense of ‘sport identity’ and the feeling of being ‘a real athlete’ from the weight making process (45). Furthermore, it may serve as a coping strategy and create an increased sense of focus and commitment (44). Although the majority of wrestlers believe that ‘making weight’ is a major activity and important aspect of their sport (44), the equivocal results of investigations on the benefits on competitive success (46-48, 52) make it difficult to draw conclusions.

In contrast to the real and/or perceived competitive benefits, many negative consequences may arise from AWL. In November 1997 three America wrestlers died while “making
weight” via food and fluid restriction, the use of vapour impermeable suits and exercise in a hot and humid environment (28). This prompted rule changes in the national competition, including reducing the recovery time post weigh-in and identifying a ‘minimum wrestling weight’ (MWW) based on pre-season body composition measurements, which have been associated with a decline in extreme AWL practices in this cohort (29). Position statements from the American College of Sports Medicine (30), The Association of Ringside Physicians (31) and the National Athletic Trainers Association (32) warn against extreme practices and recommend rule changes to discourage specific weight loss techniques and large magnitudes of AWL, as well as recommending minimum body fat levels of 5% and 12% in males and females respectively. However, these are yet to influence Olympic competitions; with many athletes who change their weight loss practices to suit the new rules for national competitions reverting to previous extreme practices when the rules permit this as is the case for international style competitions including the Olympic Games (34).

Methods, prevalence and magnitude of acute weight loss

Various methods are used by combat sport athletes to achieve AWL, with the most popular methods across all Olympic combat sports being an increase in exercise and restriction of fluid/food intake (13, 15, 20, 29, 34). Dietary changes include restricted intakes of fluid, carbohydrate, fat and/or fibre intake with reductions in total energy intake ranging from a 35% decreases during the week before weigh-in to total food restriction on weigh-in day (15, 21, 34, 55, 56). Furthermore, it has been demonstrated that athletes who lack a good understanding of nutrition are more likely to resort to extreme fasting and dehydration to achieve weight loss, than those with a better understanding (57). The magnitude of AWL before weigh-in is commonly reported at around 5% of BM across all combat athletes (13,
15, 20, 21); however, differences exist amongst sports in the ranges, time spans over which the weight is lost, and how frequently they occur.

**Performance implications of acute weight loss**

The potential for performance impairment in response to AWL techniques appears obvious, yet the impact of these practices on sport performance remains somewhat an issue of conjecture. While activities that demand high power and strength outputs are less likely to be influenced by AWL (37), performance in activities that require significant contributions of aerobic and anaerobic metabolism to energy yield are typically compromised (23). Several mechanisms have been proposed to explain the implications of AWL on performance. Hypohydration or lowered plasma volume coupled with depletion of muscle glycogen stores has been proposed to underlie the performance decrement associated with AWL (58). However, hypohydration is generally induced in combination with thermal and metabolic stress and the impact of these confounding variables on performance cannot be discounted. Other mechanisms considered in the literature include changes in enzyme activity, modified sarcoplasmic reticulum function (59) and structural changes to muscles (60). In addition, the body’s acid/base environment may change in response to a significant reduction in dietary carbohydrate intake (61). Furthermore, psychological performance is adversely influenced by body water deficits (62) although the impact of this alone on sports specific performance remains to be addressed. It has also been proposed that hypohydration alters central nervous system function (63), perhaps because of the association between hyperthermia and central fatigue (64). The increase in training load common among athletes attempting to acutely decrease BM may not be without performance implications. A combination of these
aforementioned factors may explain the findings in one study which reported increased injury rates in athletes inducing AWL >5%BM relative to those practicing less extreme AWL(65).

It is crucial to note, however, that much of the general research on AWL and performance outcomes lacks context validity for weight making sports. A key shortcoming is the failure to include a recovery period and its associated nutrition practices following the weight loss period to mimic the interval between weigh-in and the exercise bout in real-world combat sports. Indeed, in studies where ample time and appropriate recovery strategies have followed the “weigh-in”, the acute negative performance effects of the AWL have been found to be reversible (41, 66).

Another ‘real world’ aspect of the effect of AWL on performance in combat sports is the recognition that performance is measured relative to other competitors rather than an individual’s absolute best. Thus, it may not be important if AWL reduces an athlete’s performance as long as it remains better than that of an opponent. Several studies have attempted to provide insight into how BM reduction may affect competitive success. In an investigation of high school wrestling (47), where a MMW corresponding to 5% body fat was determined as a voluntary identification of the lowest weight an athlete should compete at, those competing below MMW were more likely to place in state championship qualifying tournaments than those who didn’t.

Another protocol used to examine the “real life” relationship between AWL and performance in is to compare the magnitude of the gain in BM between weigh-in and competition and competitive success. This regain of BM has been used as a surrogate for the magnitude of AWL needed to make weight. However, studies that have undertaken this protocol have produced mixed results (46, 48, 52). For example, it has been reported that large BM regains correlated with competitive advantage in high school wrestlers (46), but not in collegiate wrestlers at a national championship (52). Here it is acknowledged that success in wrestling
is determined by multiple factors including aerobic and anaerobic fitness, strength, power, psychological and emotional state and perhaps most importantly skill and technical proficiency (8). Among high school athletes, where many of these areas are not well developed, BM may contribute more to an athlete’s overall attributes than in more experienced athletes. However, in the highly selective sporting competition of college wrestlers, it is likely that the cohort consisted of a more homogenous group of already successful athletes. Furthermore BM regain for winners and losers were substantially higher (5.3±2.0% vs 5.3±2.4% respectively), compared to the high school wrestlers (2.4±1.8% vs 1.9±1.6%).

In contrast, no association was found between BM re-gain and competitive success in teenage taekwondo athletes (48) and raises physical differences in the activities involved in combat sports as a potential confounder in the importance of BM manipulations. Grappling activities, which underpin the sport of wrestling (and judo), involve the manipulation of an opponent’s BM whereas striking sports (e.g. taekwondo/boxing) are potentially more dependent on the tactical movements of one’s own BM. Indeed, it has been suggested that height plays a more pivotal role than BM in striking sports and that athletes should be separated by height rather than BM to equalise competition matchups (12). Unfortunately, there are no studies on the effect of post-weigh-in BM regain on competitive success in judo or boxing.

In summary, the final effect of AWL on combat sports performance involves a complex interaction of factors, including the method/s of AWL, the intensity, type and duration of the performance effort, environmental conditions and an individual’s fitness capacity (59). Furthermore, the rules of the sport, including the period of time between weigh-in and competition allows an opportunity for athletes to restore fluid deficits and replace carbohydrate stores, which may have been manipulated prior to weigh-in, and thus recalibrate the final performance effect. This will now be explored.
Recovery practices following acute weight loss

Although combat sport athletes recognise the importance of replacing fuel stores and restoring fluid deficits post weigh-in, many do not appear to follow best practice guidelines (18). The optimal recovery strategies will depend on the methods of AWL that have been used. Recovery from the dehydration associated with AWL is possible depending on the degree of fluid loss and the recovery time available. In the lab setting dehydration of 2.8% and changes in plasma volume are reversible following three hours of aggressive nutritional recovery (43). However, in one example during an actual wrestling competition, plasma volume and body water changes associated with dehydration of 6% BM were not completely reversed even 15 hours post weigh-in (67). Indeed, hydration assessment undertaken just before competition revealed significant levels of hypohydration in more than 80% and 95% of combat sport athletes who participated in events with weigh-ins scheduled for the evening before and the morning of the event respectively (68).

In terms of restoration or preparation of glycogen stores before competition, an assessment of the dietary practices of wrestlers following a weigh-in on the evening before competition found that reported carbohydrate intake was in general agreement with guidelines for optimal glycogen storage (69). A different study using muscle glycogen measurement via biopsy techniques confirmed the general success of athletes in preparing adequate fuel stores for competition when overnight recovery is available (70). It is unclear whether athletes who undergo weigh-in the morning of a competition can fully normalise or supercompensate muscle glycogen levels, however, such targets may not be necessary for optimal performance. Indeed, four hours of refuelling has been shown to be adequate for judo related performance (71) and glycogen stores have not be found to be limiting for performance when ad libitum intake of carbohydrate between bouts is allowed (70). Thus, aggressive refuelling
strategies involving the intake of large amounts of carbohydrate between weigh-in and competition may not be warranted.

Taken together, the apparent post-weigh-in fluid and food intake practices of combat athletes and the theoretical timelines of glycogen storage and rehydration allow the following conclusions. For combat sports that implement weigh-ins the evening before competition day, there is opportunity for adequate restoration of fluid and fuel status; furthermore, although this is probably achieved in the case of glycogen preparation, many athletes do not attain euhydration (18, 68, 70). In contrast, shorter recovery periods, as occur when weigh-in occurs on the morning of competition do not provide enough time for athletes to rehydrate when they have employed dehydration to the degree commonly practiced (13, 23, 68, 72). Furthermore, while theoretically providing enough time for sufficient (not full) glycogen restoration (70), the period between a morning weigh-in and competition time may not be well utilised by athletes (18). All of these findings highlight the importance of appropriate nutrition education for both coaches and athletes. Providing detailed recommendations is beyond the scope of this review, thus readers are directed towards published reviews on rehydration (73) and glycogen restoration (74).
Section 2.

Understanding the physiology of acute weight loss

During the process of AWL, BM is lost from various compartments of the body with measurement artefacts sometimes obscuring the real shifts and losses involved. A small amount of body fat is lost as a result of several days of energy restriction (75, 76), but significant reductions in measurements of lean mass are also observed (75, 77). Changes in lean mass measurements associated with restriction of energy, carbohydrate and fluid appear to be essentially reversed after post-weigh-in recovery or post-competition. This suggests they are associated with loss of muscle water and substrates (e.g. glycogen) rather than loss of contractile proteins. This theory is supported by evidence of reductions in total body water with weight making (77) and a halving of biopsy-derived values of muscle glycogen during a 72 hour AWL protocol where there was a loss of 5% BM (70). A significant reduction in the intake of dietary fibre and total food mass associated with food restriction (18, 55, 78) is also likely to cause a loss of BM as a consequence of reduced gastrointestinal contents and fluid in the intestinal lumen bound to dietary fibre (79). This section will address each of these potential areas of BM change during AWL, with the intent of understanding how they can be best manipulated to minimise health risks and optimise performance.

Body water and acute weight loss overview

Water makes up about 60% of the human body (80); this varies within and between different population types and is likely to be higher in combat sport athletes due to their relatively high levels of lean mass (8). Given the size of this body compartment and the speed and ease of its manipulation in comparison to other contributors to BM, it is logical that it is a primary focus of the AWL strategies of combat sport athletes.
There are three separate strategies that can be used to achieve an acute reduction in body water content: the consumption of less fluid (fluid restriction) in relation to normal daily losses; the ‘unlocking’ of bound body fluid, will in turn be excreted; and the promotion of additional fluid loss. Fluid restriction is an obvious means to reduce total body water and plays a well-documented role in the AWL practices of combat athletes (15, 21, 34, 55, 56).

Reductions in fluid compartments in the body can be derived from losses from both intracellular and extracellular stores, and include ‘free water’ or ‘bound water’. Bound water, which has the potential to be eliminated, includes that in glycogen stores and also that drawn into the intestinal space due to the presence of food matter with absorptive properties, such as fibre containing foods. The excretion of water from the body is accomplished via respiration, urination and perspiration (sweating).

**Respiration and water loss**

Respiratory water losses are affected by pulmonary ventilation, plus the temperature and humidity of inspired air. In temperate environments, these losses are approximately equal to the amount of water generated through aerobic metabolism; roughly 250-350mL per day, increasing with respiratory rate as exercise intensity increases (80). While altitude doesn’t significantly alter respiratory water losses (81), large decreases in humidity (from 80% to 20%) can dramatically affect respiratory water losses, particularly during exercise where losses increase from 0.8 to 2.7ml/min (82). Oral exhalation increases net respiratory water losses by up to 46% compared to nasal exhalation (83).

It should be noted that some bound water is released during aerobic metabolism and expelled via respiration (80) ; however, the ability to acutely manipulate this type of bound water is minimal, and the minor amount (relative to other paths of fluid loss) can essentially be
disregarded in the context of AWL. Total daily respiratory water losses range from 400mL/day in sedentary individuals in temperate environments up to 1500mL/day during times of exercise in low humidity (82). In terms of AWL strategies, exposure to a low humidity environment in the day(s) prior to weigh-in provides a passive method to significantly increase water losses, while exercising in this environment allows the addition of increased insensible loss to sweat losses.

**Urination and water loss**

Urine production is the body’s primary method of regulating fluid balance. This process is tightly controlled by the renal system, with aldosterone and antidiuretic hormone triggering renal responses to conserve or release fluid and sodium, thus maintaining body water and plasma sodium concentration. Depending on other contributions to body fluid balance, typical daily urine losses are in the range of 1-2L per day (80, 82), however are significantly decreased as dehydration progresses (84). Obligatory rates of urine production to allow the elimination of body waste products are 0.5L /d and thus, set the low level of the range of daily losses, while fluid intakes greater than the maximal rate of urine production of 18/L can lead to hyponatremia/water intoxication (85, 86). Encouraging polyuria against the tide of hydration status presents another strategy of AWL, with protocols including, sleeping or laying with the head tilted downward (87) and acute intake of high doses of vitamin C (88). Mechanisms underpinning the increased urine production in the former relating to disturbances in fluid and sodium homeostatic regulators caused by prompt increases in central blood volume (87).

Combat sport athletes have been reported to use pharmacological diuretics to promote greater urine loss in spite of their inclusion on the World Anti-Doping Agency’s List of Prohibited
Substances (16, 21). Herbal diuretics that have been shown to be effective in facilitating polyuria (89) may also be used, although this activity is morally questionable with respect to doping and may result in performance decrements due to preferential plasma volume losses, as is the case for their pharmacological counterparts (90).

One novel but largely untested method reportedly used by combat sport athletes to increase urine production/losses is the process of ‘water loading’ (91). Anecdotally, it is claimed that excessive water intake over a few days promotes polyuria that persists beyond the period of increased fluid intake and thus, achieves a net decrease in body water (92). This remains to be confirmed through scientific investigation, however if successful could provide an effective means of fluid loss albeit with the potential side-effect of promoting the potentially dangerous outcome of hyponatremia via water intoxication (86).

**Sweating and water loss**

Although urination may account for the majority of fluid losses in the general population in temperate environments, in hot/humid environments, perspiration (or loss of sweat) associated with thermoregulatory activities accounts for the majority of fluid losses (80). Furthermore, in all environments, the thermal challenge provided by exercise increases sweat losses, with a range of sweat rates being observed across individuals, exercise protocols and environmental conditions (80).

The facilitation of body fluid loss via sweating can include active (exercise induced) or passive (exposure to hot environment) strategies and is the most common method of acute BM manipulation undertaken by combat sport athletes (13, 15, 93). This observation is not surprising since sweat rates of up to 2 L/h can be achieved and represent a rapid way to achieve relative large BM losses (80).
Body sweat response is driven by a number of factors including core temperature and skin temperature. The onset of sweating can be altered by changes in plasma electrolyte concentration, plasma volume and total body water content; however, these cannot be manipulated to enhance sweat losses without the introduction of more fluid into the body, which is counterproductive to the goal of AWL (94). However, heat acclimation, adaption to exercise training and increased skin temperature are useful in increasing sweat losses (94). It should be noted however, that females produce less sweat than males and are less responsive to the effects of training adaption on sweat rate and sweat temperature threshold (95). This has been attributed to peripheral vasodilation and hormonal differences (95).

It is important to note the differences in physiological response to passive versus active sweating. Passive sweating prior to exercise decreases plasma volume, sweat rate and stroke volume during exercise, contributing to an increase in serum osmolality, heart rate and body heat storage. These physiological changes occur to a lesser extent when hypohydration develops only during exercise (96). Thus, a combination of fluid restriction and active dehydration may be the most practical way to induce dehydration in order to acutely reduce BM while minimising performance decrements. Athletes should make use of existing training sessions to promote active dehydration in preference to additional ‘sweat training’. Further passive sweating should be used only when necessary and when ample time is available for recovery. If utilising saunas as means to facilitate perspiration, dry heat saunas should be used in preference to steam saunas as it has been demonstrated that fluid loss for a given period of time is greater (up to double the rate of loss) and results in less physiological strain (97).
Sodium intake and water loss

The human body tightly regulates the osmotic pressure of body fluids through renal excretion and retention of electrolytes and fluid. It is commonly accepted the increased intake of sodium leads to increased retention of fluid, and that the reverse is true also (73, 80). This explains the common health guideline to lower sodium intake in order to lower blood volume and thus, blood pressure. In one study, hypertensive subjects lost 1-2% BM following a low sodium diet (<500mg) for five days, although no interim measures were taken to establish the time frame of weight (98). While a reduction in salt intake has been shown to significantly reduce blood pressure in hypertensive people and to a lesser extent in normotensive people (99), indicating a decrease in intravascular fluid retention, this may not translate to alterations in BM in all people. Nevertheless, it has become a practice among some combat sport athletes to reduce sodium below habitual intakes during the weight cutting period (55). While this may not influence total body water per se, when used in combination with other fluid manipulation strategies it may ‘release’ more body water and allow a reduction in BM. This remains to be confirmed by empirical research.

Glycogen, bound water and acute weight loss

Dietary carbohydrate is stored in skeletal muscle and liver tissue as glycogen and acts as an energy reserve that can be quickly mobilized when there is a need for glucose. Glycogen is a branched bio-polymer of glucose that has been noted to bind to water at a ratio of 1: 2.7 (water: glycogen) (100). Furthermore glycogen storage may contribute up to 8% of liver weight and 1-2% of skeletal muscle weight (101, 102). Thus, based on calculation of the male body being 60-65% muscle mass (103) with an average liver weight of 1.56 kg (104), a 75 kg male may potentially store 462 g and 1665-3610 g of glycogen and bound water in the liver.
and skeletal muscle, respectively. Of course the validity of these estimations are limited by the accuracy of measurements of glycogen: water ratios, and the stability of this ratio in different tissues and across different glycogen concentrations (82). Nevertheless, manipulation of the glycogen stores provides another strategy to achieve AWL by athletes. Two methods are available to achieve this: 1- to consume a low carbohydrate diet to prevent the restoration of muscle glycogen stores following their depletion via the normal training program and 2- to perform additional exercise in order to deplete glycogen reserves more rapidly. Issues determining the benefits/disadvantages of each approach include the effects of additional exercise in the period just prior to the weigh-in/event, versus the effect of a more chronic period of carbohydrate depletion on programmed training leading into the competition.

Data from the available literature show that 7 days of a low carbohydrate diet, combined with training and a slight reduction in energy (<10%) can achieve a BM reduction of ~ 2% while maintaining performance of strength/power measures and a 30 s Wingate test (105). Similar findings have been demonstrated by others following 2 weeks of a low carbohydrate diet (106). However, 6 weeks of a low carbohydrate diet was associated with increased RPE during exercise and decrements in power and endurance, which the authors attributed to losses in lean mass (107). Together these findings have several implications for combat sport athletes:

1. The adoption of a low carbohydrate diet is an effective means to decrease BM in order to make weight (via the loss of glycogen and bound water);

2. It may not be crucial to replenish glycogen stores when the recovery period between weigh-in and competition is minimal, and
3. A viable weight making strategy for sports with multiple weigh-ins across consecutive days (i.e. amateur boxing) may involve the reduction of BM via a low carbohydrate diet prior to the first weigh-in, with the maintenance of this strategy over the course of competition period and opportunities for acute rehydration and intake of adequate carbohydrate for each bout.

The magnitude of possible BM loss and the strategies needed to achieve it (i.e. the level of carbohydrate restriction and the time frame required to produce maximal BM loss) will depend on glycogen status and training load prior to commencement of the strategy. Restricting carbohydrate intake to less than 50 g per day (combined with a small reduction in energy) should be enough to facilitate 1-2% BM loss based on existing research (105) and the reported carbohydrate intakes of combat sport athletes (55, 78).

**Gut contents and acute weight loss**

Many fighters have been reported to reduce portion sizes and total food volume prior to weigh-in in order to reduce mass of intestinal contents and contribute to total loss of BM (15, 21, 34, 55, 56). The use of bowel preparation formulas (used in clinical situations to prepare for gut surgery) or laxatives is not uncommon amongst weight category sport athletes, presumably to facilitate the expulsion of intestinal contents and promotion of AWL, possibly equating to 1 kg (108). The prevalence of laxative use and/or vomiting has been reported to be around 10% in combat sport athletes (21, 109). While these methods may be effective in cleansing the colon and removing intestinal bulk, the specific use of bowel preparation formulas (typically containing osmotic laxatives and purgatives) has been shown to reduce exercise capacity (108). Therefore, dietary strategies to reduce total food volume may be a preferable way to manipulate the mass of intestinal contents while maintaining performance.
goals. This might include a switch to consumption of foods that are energy-dense in the hours and days prior to weigh-in to maintain energy and macronutrients intakes with a smaller food mass. This would be particularly important for those whose weigh-in times are within several hours of competition time, and thus have limited potential to effectively rehydrate and refuel between weigh-in and competition.

Dietary fibre can both slow transit time of foods through the bowel and draw water into the intestinal space, adding bulk to stools. Different foods possess different faecal bulking properties (79) but it is assumed that if a person reduces their habitual consumption of ‘bulking’ fibre-rich foods’, it will reduce the mass of undigested plant matter, the amount of water drawn into the intestinal space and faecal bulk, favourably lowering BM. Indeed, a linear relationship exists between fibre intake and bowel cleanliness in pre colonoscopy patients (110), and the adoption of a low fibre diet for even two days helps to cleanse the bowel (relative to higher fibre diets)(110) with seven days of less than 10g fibre per day being equally as effective as a protocol involving a bowel preparation formula (Selg, 1000®; Promefarm, Milan, Italy)(111). Additionally low fibre diets result in less physiological stress and symptoms than a bowel preparation formula (111). For combat sport athletes, the ability to continue to train throughout the bowel emptying process is an important consideration.

Despite the available research on the bowel emptying effects of low fibre diets, and the evidence that many fighters adopt low fibre diets during the final days before weigh-in (55), there are no specific investigations on the success of this approach on the outcomes of weight-making and the magnitude of the weight change it might achieve. Additionally, since whole gut transit times vary widely between individuals from 10-96 hours (112), precise guidelines for the use of fibre restriction for AWL cannot be determined at this stage. Further investigation in the application of low residue formulas to weight making is warranted, including the potential for weight loss, along with health and performance implications.
Section 3.

Conclusion and practical applications

Athletes currently engage in varying degrees of fluid deprivation, food restriction and increased exercise during protocols aimed at achieving AWL. In light of the information discussed throughout this review, recommendations can be devised to refine weight making practices of combat sport athletes. While some form of dietary restriction is generally necessary to facilitate AWL, the most effective strategy to achieve an AWL while allowing restoration of performance after the weigh-in is to consume strategic amounts of energy from low weight/low fibre foods while inducing a mild fluid deficit. Greater fluid deficits and depletion of glycogen stores provide an additional strategy for those requiring greater weight losses. Optimal post-weigh-in recovery strategies are influenced by method(s) used to achieve AWL. Figure 1 provides a decision tree to help coaches and athletes plan an appropriate weight making strategy.
Figure 2.1 ‘Weight making plan’ decision tree

*Duration of carbohydrate restriction required to maximally reduce glycogen mass will vary depending on current glycogen status and training volume/intensity in the 7 days prior to weigh-in. For athletes engaged in greater training loads, fewer days of carbohydrate restriction will be required to deplete glycogen stores.

**Duration of fibre restriction required to maximally reduce gut contents will vary depending on individual whole gut transit time, athletes should note individual responses to low fibre intakes.
It is important to note that circumstances will vary between sports and individuals. By monitoring day-to-day and within day fluctuations in BM, athletes and coaches can better understand the acute management of BM. Athletes should trial their weight making and recovery practices prior to important competitions, record their experiences and continually reflect on the process from one weigh-in to the next.
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Chapter 3
STUDY ONE

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\textbf{“Weight management practices of Australian Olympic combat sport athletes”}

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Abstract

Purpose: Combat sport athletes undertake chronic and rapid weight loss (RWL) practices to qualify for weight divisions lower than their training weight. Variation between sports in the prevalence, methods, and magnitude of weight loss as well as recovery practices may be influenced by factors including competition level and culture. Differences in methodologies of previous research in combat sports make direct comparisons difficult, thus this study aimed to examine weight loss practices among all Olympic combat sports in Australia, using standardised methodology. Methods: High calibre competitors in wrestling, boxing, judo and taekwondo (n=260) at Australian competitions were surveyed using a validated tool which provides quantification of how extreme an athlete’s weight loss practices are; the RWL score (RWLS). Additional qualitative and quantitative survey data were also collected. Results: Neither sport, sex or weight division group had an effect on RWLS however a significant effect of athlete calibre was detected [F (2,215) = 4.953, MSE = 4.757, p = 0.00792]. Differences between sports were also evident for: most weight ever lost in order to compete [H = 19.92, p = 0.0002), age at which weight cutting began (H = 16.34, p = 0.001) and selected methods/patterns of RWL (p < 0.001). Weight cycling between competitions was common among all sports as were influences on athlete’s behaviours. Conclusions: While many similarities in weight loss practices and experiences exist between combat sports, specific differences were evident. Nuanced, context/ culturally specific guidelines should be devised to assist fighters’ in optimising performance while minimising health implications.
Introduction

All Olympic combat sports (currently, judo, taekwondo, boxing and wrestling) separate athletes by body mass (BM) into “weight” divisions to minimise size/strength disparities. To ensure athletes meet weight requirements, official weigh-ins are held before competition. In addition to reducing body fat to lower BM, fighters’ commonly ‘exploit’ the notion of weight divisions by competing in a division below their “training weight” (16). This is commonly achieved via rapid weight loss (RWL) in the hours and days (potentially up to a week) before the official weigh-in, before utilising the period between the weigh-in and competition to reverse RWL, subsequently presenting to competition significantly heavier than at weigh-in(41, 113).

While various approaches to RWL exist, dehydration and food restriction are the most common methods and, together, result in alterations in body water, fuel availability and reductions in gut contents (113). Recent reports, however suggest athletes use novel and untested methods to reduce BM in addition to traditional means, including “water loading” (consuming large fluid volumes for several days before a fluid restriction to create an “overshoot” in hormonal regulation of body water), sodium restriction, and sleeping with the head tilted down to alter body fluid distribution (91). Position statements from various sports medicine bodies warn against RWL (30-32), citing health risks and performance implications. While even small degrees of dehydration may affect aerobic performance (23) and greater magnitudes impact anaerobic performance (5, 8, 114) in other sports, these findings may not be relevant to combat sports which allow recovery from dehydration post weigh-in. Indeed some have even suggested a degree of adaptation to RWL may take place, however this is still debated (66, 115). Another factor supporting the continuation of RWL is the potential to consume fluids and foods between weigh-in and competition, thereby reversing sub-optimal nutritional status. Key factors in the success of such strategies are the
time and opportunity to consume relevant nutrients. Although fighters utilise this recovery time to rehydrate and refuel (16, 71), differences in weigh-in regulations and weight divisions between combat sports affect these recovery efforts.

Factors aside from competition regulations and physiological requirements influence weight loss practices, including; psychology, level of competition, sporting culture, as well as the wider environment (16, 49). For example, differences in practices are seen between wrestlers of different countries (20, 22), and between combat sports athletes within the same country (15, 116). Furthermore, most fighters begin losing weight for competition from 13-17 y of age, although RWL in athletes as young as 7y is noted (15, 20-22). Examinations of wrestlers have correlated the prevalence and magnitude of RWL with competition level (20, 22), and although this has occasionally been shown in judo (21, 117), other researchers failed to confirm these findings and suggest a lower prevalence of RWL (15).

At present, much of the information and support provided to fighters is generic rather than targeted to each sport. Given the rich literature on RWL practices, it would be valuable to collate and compare data across sports. Unfortunately, attempts to do this have been impeded by differences in study methodologies such as data collection methods, survey tools, population sampling protocols and the calibre/competitive level of subjects. Therefore, a more uniform approach is needed. We have identified useful tools which are applicable across combat sports, such as the work by Artiolli et al. (118) which quantifies the extent of athletes’ RWL practices. This specific tool has been applied to both judo and taekwondo athletes (17, 21, 119), however by implementing it in a standardised manner across all Olympic combat sports, data will be able to be directly compared between sports.

Accordingly, the aim of this study was to conduct a standardised survey of RWL practices undertaken by fighters at high level competitions within a single country (Australia). Issues of interest included magnitude and strategies of weight loss and regain following weigh-in
and sources of influence regarding these practices. Furthermore, we sought to gain insight into athletes’ use of novel strategies of RWL.
Methods

Overview

Elite athletes participating in nationally significant Olympic combat sport competitions in 2015 were recruited to take part in a questionnaire-based observational study of RWL practices. Competitions included: the ACT International Judo Open (Judo Federation Australia); the Australian National Amateur Boxing Championships (Boxing Australia); the World Championships Australian Team Selection Trials (Sports Taekwondo Australia); and the Australian National Championships (Wrestling Australia). The study was approved by the Higher Research Ethics Committee at the University of Sunshine Coast in Queensland, Australia and participants provided informed consent after having the study explained to them verbally and in writing.

Survey design

The survey, designed to gain insight into athletes’ historic and current weight loss practices, was administered after the athletes’ first weigh-in and involved two parts. The first section was based on the RWL questionnaire (RWLQ) of Artioll and co-workers (118), developed from a study of wrestlers and validated in a sample of Brazilian judo athletes. The original questionnaire was validated by a group of experts and shown to correlate well with an externally validated questionnaire (RestRAINT scale) and to clearly distinguish between groups of athletes with known differences in weight loss practices (118). Although validation was undertaken in judo athletes, the majority of questions focus on generic information (diet history, weight loss practices, competition level and influences). The judo-specific questions are easily modified enabling them to be applied across combat sports. For example; “at what age did you begin training judo?” is easily modified to “at what age did you begin training boxing/taekwondo/wrestling?”. No question exists on the questionnaire which is not easily
modified in this way. Aside from qualitative and descriptive information, the RWLQ provides a validated RWL score (RWLS) which allows a quantitative measure of the aggressiveness of one’s weight management behaviour. Small amendments to the questionnaire for the current study involved the inclusion of questions regarding several novel RWL practices anecdotally used by fighters.

The second section questioned participants about weight loss practices used in the current competition. This section includes questions related to fluid restriction, the use of passive (sauna, heated rooms, sweat suits) and/or active (exercise induced) sweating as well as strategies used to manipulate gut contents. Separating chronic BM loss (i.e. fat and muscle loss) from acute weight loss (body water and gut contents) can be difficult in the lead up to weigh-in as these often overlap. Nevertheless in order to gain insight into athletes use of chronic and RWL we determined BM loss in the week preceding weigh-in to be indicative of RWL as others have found little fat loss to occur in combat sport athletes during this time (120). Furthermore investigations have previously observed a period of six days prior to weigh-in being used for RWL (41). Thus, athletes were asked to quantify BM loss in the past week, two weeks and month, to distinguish between chronic and RWL. In view of modifications made to the original RWLQ, the survey was screened for readability and content validity by a separate group of combat athletes and experts including sports dietitians from the Australian Institute of Sport. A reliability study of the modified questionnaire was conducted utilising the same methodology of the original (118). Similar results were revealed with; questions providing parametric answers showing high intra class coefficients (>0.9) calculated according to the methods advocated by Weir (121), dichotomous answers being replicated in >80% of instances and subjects reporting the same responses within ±1 point in >80% of instances on the 5-point scale questions. The final tool is provided as supplementary information to this paper (see appendix).
Data analysis

Descriptive statistics (i.e. mean, SD and frequency analysis) were used to display subject characteristics and responses to survey questions providing ordinal data. *D'Agostino-Pearson and Levene’s tests were used to assess normality and homogeneity respectively.* For between sport comparisons of non-parametric continuous data, Kruskal Wallis tests were used followed by Dunn’s test for multiple comparisons. The RWLS’s of athletes within and between sports were analysed by sex, ‘weight division group’ and ‘calibre’ using two-way ANOVA with Bonferroni post-hoc tests, following square root transformation in order to achieve normality. As weight divisions differ between sports, they were collapsed evenly into three categories; ‘light weights’, ‘middle weights’ and ‘heavy weights’, with those competing in divisions with no upper weight limit excluded from this analysis. Athletes who had medalled at international competition(s) were deemed ‘highest calibre’, those who medalled at national competition were deemed ‘moderate calibre’, and all others were classified ‘lesser calibre’. Contingency tables were constructed and chi-square tests performed to investigate the effect of sport on preferences for acute versus chronic weight loss, plus methods of body water and gut content manipulation. When data were transformed to achieve normality, statistical analyses were completed on the transformed data, with back transformed data being displayed in tables and figures for ease of visualisation (122). Analysis was completed using PRISM v 6.0 (GraphPad Software, San Diego, California, USA). All data are expressed as mean ± SD unless otherwise noted. Athletes indicating no weight loss prior to the current competition were excluded from some analyses; this is indicated alongside the findings.
Results

We estimate 95-100% of the athletes participating in the competitions examined were approached to take part in the survey. Non response rate (including surveys which were unable to be used) was ~30% of the wrestling athletes and ~25% of all other athletes who competed in the examined competitions. Participant characteristics are displayed in Table 3.1, with competitive success summarised in Table 3.2. Almost 90% of participants reported losing weight for past competitions; athletes’ characteristics and their RWLS are displayed in table 3.3.

Table 3.1 Subject characteristics and lifetime experience of weight making for competition

<table>
<thead>
<tr>
<th></th>
<th>Sex (Male %/ Female %)</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Competition experience (years)</th>
<th>Prevalence of weight loss within competition preparation (lifetime experience) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxing n=75</td>
<td>73/27</td>
<td>23.8 ±5.6</td>
<td>66.4 ±12.4</td>
<td>173.9 ±9.6</td>
<td>6.2 ±3.8</td>
<td>95</td>
</tr>
<tr>
<td>Judo n=82</td>
<td>65/35</td>
<td>22.3 ±7.8</td>
<td>73.6 ±24.7</td>
<td>171.9 ±11.6</td>
<td>8.9 ±6.7</td>
<td>82</td>
</tr>
<tr>
<td>Taekwondo n=65</td>
<td>48/52</td>
<td>22.5 ±4.7</td>
<td>65.4 ±13.3</td>
<td>173.7 ±10.6</td>
<td>9.3 ±5.1</td>
<td>88</td>
</tr>
<tr>
<td>Wrestling n=38</td>
<td>82/18</td>
<td>25.2 ±6.2</td>
<td>74.3 ±12.3</td>
<td>174.0 ±7.7</td>
<td>8.6 ±7.4</td>
<td>90</td>
</tr>
<tr>
<td>Combined n=260</td>
<td>65/35</td>
<td>23.2 ±6.3</td>
<td>69.5 ±17.8</td>
<td>173.2 ±10.3</td>
<td>8.2 ± 5.8</td>
<td>88</td>
</tr>
</tbody>
</table>
Table 3.2 Frequency analysis of subjects reported competitive success

<table>
<thead>
<tr>
<th></th>
<th>Reported winning a medal at regional competition (%)</th>
<th>Reported winning a medal at state competition (%)</th>
<th>Reported winning a medal at national competition (%)</th>
<th>Reported winning a medal at international competition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxing n=75</td>
<td>88</td>
<td>92</td>
<td>52</td>
<td>24</td>
</tr>
<tr>
<td>Judo n=82</td>
<td>94</td>
<td>87</td>
<td>76</td>
<td>49</td>
</tr>
<tr>
<td>Taekwondo n=65</td>
<td>99</td>
<td>99</td>
<td>95</td>
<td>71</td>
</tr>
<tr>
<td>Wrestling n=38</td>
<td>74</td>
<td>79</td>
<td>74</td>
<td>47</td>
</tr>
<tr>
<td>Combined n=260</td>
<td>90</td>
<td>90</td>
<td>74</td>
<td>47</td>
</tr>
</tbody>
</table>

Table 3.3 Subject characteristics and Rapid Weight Loss Scores of combat athletes who have undertaken weight loss during competition preparation*

<table>
<thead>
<tr>
<th></th>
<th>Sex (Male %/ Female %)</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Competition experience (years)</th>
<th>Rapid weight loss score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxing n=71</td>
<td>75/25</td>
<td>24.9 ±4.9</td>
<td>65.6 ±11.3</td>
<td>173.6 ±9.4</td>
<td>6.4 ±3.8</td>
<td>30.5 ±11.0</td>
</tr>
<tr>
<td>Judo n=68</td>
<td>62/38</td>
<td>22.9 ±7.3</td>
<td>68.3 ±15.8</td>
<td>170.5 ±10.5</td>
<td>9.0 ±6.4</td>
<td>29.5 ±9.7</td>
</tr>
<tr>
<td>Taekwondo n=57</td>
<td>47/53</td>
<td>22.5 ±4.6</td>
<td>64.2 ±12.1</td>
<td>173.2 ±10.5</td>
<td>9.1 ±5.1</td>
<td>31.7 ±11.3</td>
</tr>
<tr>
<td>Wrestling n=33</td>
<td>79/21</td>
<td>25.0 ±6.3</td>
<td>72.4 ±11.1</td>
<td>173.1 ±7.4</td>
<td>8.7 ±7.4</td>
<td>31.4 ±11.5</td>
</tr>
<tr>
<td>Combined n=229</td>
<td>65/35</td>
<td>23.1 ±5.9</td>
<td>67.0 ±13.2</td>
<td>172.5 ±9.8</td>
<td>8.2 ±5.7</td>
<td>30.6 ±10.8</td>
</tr>
</tbody>
</table>

Table 3.4 displays survey responses. Sport was found to have an effect on: most weight ever cut, (H = 16.32, p = 0.001); number of times competed last year/season, (H = 19.92, p = 0.0002); and age at which weight cutting began, (H = 16.34, p = 0.001). Post hoc tests revealing specific differences are displayed in table 3.4.
Table 3.4 Subject survey responses stratified by sport*

<table>
<thead>
<tr>
<th>Question</th>
<th>Boxing</th>
<th>Judo</th>
<th>Taekwondo</th>
<th>Wrestling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did you change weight class in the past two years?</td>
<td>48%</td>
<td>46%</td>
<td>56%</td>
<td>76%</td>
</tr>
<tr>
<td>Off season weight above weight division (% of division)</td>
<td>5.0 ±5.8</td>
<td>3.6±5.7</td>
<td>4.5±5.8</td>
<td>6.3±8.4</td>
</tr>
<tr>
<td>What is the most weight you have ever lost in order to compete in your career (BM%)</td>
<td>8.3 ±4.9</td>
<td>6.9 ±3.0</td>
<td>9.3 ±4.5$</td>
<td>11.0 ±6.5$</td>
</tr>
<tr>
<td>How many times did you compete last season/year</td>
<td>8.2 ±4.2$</td>
<td>6.8 ±4.7</td>
<td>7.4 ±3.8$</td>
<td>4.5 ±4.2</td>
</tr>
<tr>
<td>How many times did you cut weight in order to compete in last season/year (% of competitions)</td>
<td>68.2 ±32.4</td>
<td>70.6 ±32.0</td>
<td>70.1 ±30.0</td>
<td>60.0 ± 35.7</td>
</tr>
<tr>
<td>How much weight do you usually cut before competitions (BM%)</td>
<td>3.6 ±2.1</td>
<td>3.8 ±2.2</td>
<td>4.6 ±2.9</td>
<td>4.9 ±3.7</td>
</tr>
<tr>
<td>In how many days do you usually cut weight before competitions (days)</td>
<td>12.3 ±10.3</td>
<td>11.3 ±8.3</td>
<td>16.9 ±15.7</td>
<td>10.0 ±8.1</td>
</tr>
<tr>
<td>At what age did you begin to cut weight for competitions</td>
<td>19.3 ±4.9#</td>
<td>17.1 ±5.5</td>
<td>17.3 ±4.0</td>
<td>20.5 ±8.7</td>
</tr>
<tr>
<td>How much weight do you usually regain in the week after competition (BM%)</td>
<td>4.1±2.4</td>
<td>3.6 ±2.0</td>
<td>4.6 ±2.6</td>
<td>4.8 ±3.6</td>
</tr>
</tbody>
</table>

* excludes athletes who reported no lifetime experience of weight loss in competition preparation
# denotes different to judo (p=<0.05), $ denotes different to wrestling (p=<0.05)

Table 3.5 displays frequency of use of different weight loss methods.
Table 3.5 Frequency analysis of different methods of body mass loss by sport* (n = 229)

<table>
<thead>
<tr>
<th>Method</th>
<th>Always (%)</th>
<th>Sometimes (%)</th>
<th>Almost never (%)</th>
<th>Never used (%)</th>
<th>Don’t use anymore (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradual dieting</td>
<td>53.6  48.7  50.8  45.4</td>
<td>38  27.9  40.4  27.3</td>
<td>2.8  10.2  7  6.1</td>
<td>2.8  10.2  0  18.2</td>
<td>2.8  3.0  1.8  3</td>
</tr>
<tr>
<td>Skipping 1 or 2 meals</td>
<td>7.0  20.6  15.8  36.4</td>
<td>49.3  33.7  56.2  30.3</td>
<td>18.3  26.5  10.5  18.2</td>
<td>21.2  13.3  10.5  12.1</td>
<td>4.2  5.9  7  3</td>
</tr>
<tr>
<td>Fasting (not eating all day)</td>
<td>5.6  25.0  10.5  27.3</td>
<td>18.3  29.3  49.2  42.4</td>
<td>19.7  13.3  17.5  9.1</td>
<td>52.2  26.5  17.5  18.2</td>
<td>4.2  5.9  5.3  3</td>
</tr>
<tr>
<td>Restricting fluid ingestion</td>
<td>22.5  41.3  35.1  36.4</td>
<td>49.3  33.6  47.3  45.4</td>
<td>14.1  16.2  8.8  9.1</td>
<td>11.3  7.4  5.3  9.1</td>
<td>2.8  1.5  3.5  0</td>
</tr>
<tr>
<td>Increased exercise (more than usual)</td>
<td>22.5  35.1  28.1  37.7</td>
<td>54.9  38.3  52.6  29</td>
<td>11.3  11.8  12.3  12.1</td>
<td>8.5  11.8  3.5  18.2</td>
<td>2.8  3  3.5  3</td>
</tr>
<tr>
<td>Training intentionally in heated rooms</td>
<td>7.0  11.8  7.0  9.1</td>
<td>42.3  22.1  22.8  37.8</td>
<td>22.5  25  32.5  15.3</td>
<td>25.4  38.2  34.2  37.8</td>
<td>2.8  2.9  3.5  0</td>
</tr>
<tr>
<td>Saunas</td>
<td>11.3  24.9  12.3  12.1</td>
<td>45.1  28  43.8  54.6</td>
<td>22.5  22.1  21.1  18.2</td>
<td>18.3  22.1  17.5  12.1</td>
<td>2.8  2.9  5.3  3</td>
</tr>
<tr>
<td>Training with rubber/plastic suits</td>
<td>15.5  8.9  10.5  9.1</td>
<td>53.5  25  12.3  28.8</td>
<td>9.9  19.1  15.8  18.2</td>
<td>19.7  44  57.9  40.9</td>
<td>1.4  3  3.5  3</td>
</tr>
<tr>
<td>Use of rubber/plastic suits outside of training times</td>
<td>2.8  3.0  0.0  3.0</td>
<td>9.9  7.4  1.8  6.1</td>
<td>16.9  13.3  12.3  15.2</td>
<td>67.6  68.9  80.6  72.7</td>
<td>2.8  7.4  5.3  3</td>
</tr>
<tr>
<td>Spitting</td>
<td>4.2  5.9  0.0  3.0</td>
<td>25.4  13.3  14  21.2</td>
<td>21.1  23.6  7  9.1</td>
<td>47.9  54.3  70.2  60.6</td>
<td>1.4  2.9  8.8  6.1</td>
</tr>
<tr>
<td>Laxatives</td>
<td>0.0  0.0  3.5  0.0</td>
<td>8.5  8.9  10.5  3</td>
<td>12.7  13.3  14  6.1</td>
<td>76  76.3  63.2  84.8</td>
<td>2.8  1.5  8.8  6.1</td>
</tr>
<tr>
<td>Diuretics</td>
<td>0.0  0.0  1.8  0.0</td>
<td>9.9  3  3.5  3</td>
<td>5.6  10.4  8.8  6.1</td>
<td>83.1  82.1  80.6  87.9</td>
<td>1.4  4.5  5.3  3</td>
</tr>
<tr>
<td>Diet pills</td>
<td>1.4  0.0  0.0  0.0</td>
<td>1.4  0  1.8  3</td>
<td>7  11.6  3.5  0</td>
<td>88.8  82.4  92.9  94</td>
<td>1.4  6  1.8  3</td>
</tr>
<tr>
<td>Vomiting</td>
<td>0.0  0.0  0.0  0.0</td>
<td>0  0  3.5  6.1</td>
<td>4.2  7.4  7  0</td>
<td>94.4  86.6  84.2  90.9</td>
<td>1.4  6  5.3  3</td>
</tr>
<tr>
<td>Low salt diet</td>
<td>8.5  11.8  15.8  15.2</td>
<td>28  17.9  35.1  15.2</td>
<td>10  10.3  1.8  12.1</td>
<td>50.7  57  45.5  54.5</td>
<td>2.8  3  1.8  3</td>
</tr>
<tr>
<td>Low residue/low fibre diet</td>
<td>2.8  11.8  15.8  3.0</td>
<td>21.1  20.6  21.1  15.2</td>
<td>18.3  11.8  12.3  15.2</td>
<td>56.4  52.8  49  63.6</td>
<td>1.4  3  1.8  3</td>
</tr>
<tr>
<td>Low weight/high energy food</td>
<td>9.9  20.6  19.3  12.1</td>
<td>22.5  25  36.9  45.5</td>
<td>26.8  10.3  14  9.1</td>
<td>39.4  41.1  26.3  30.3</td>
<td>1.4  3  3.5  3</td>
</tr>
<tr>
<td>Water loading</td>
<td>8.5  3.0  5.3  21.2</td>
<td>11.3  26.5  21.1  21.2</td>
<td>19.7  13  5.3  12.1</td>
<td>57.7  53  63  45.5</td>
<td>2.8  4.5  5.3  0</td>
</tr>
<tr>
<td>Sleeping with head tilted downwards</td>
<td>0.0  0.0  0.0  0.0</td>
<td>0  0  0  3</td>
<td>5.6  7.5  0  0</td>
<td>93  88  96.5  94</td>
<td>1.4  4.5  3.5  3</td>
</tr>
</tbody>
</table>

B = boxing, J = Judo, T = Taekwondo, W = wrestling  *excludes athletes who reported never losing weight in competition experiences.
Frequency analyses of persons influencing weight loss practices are displayed in table 3.6. In general; coaches, other athletes and former athletes were the greatest influences across all sports with parents, doctors and dietitians provide less influence.
Table 3.6 Frequency analysis of the persons who are influential on the weight management behaviours reported by participants across sports* (n=229)

<table>
<thead>
<tr>
<th>Role</th>
<th>Not influential (%)</th>
<th>A little Influential (%)</th>
<th>Unsure (%)</th>
<th>Somewhat influential (%)</th>
<th>Very influential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Another athlete</td>
<td>21.4</td>
<td>27</td>
<td>26.8</td>
<td>46.9</td>
<td>24.3</td>
</tr>
<tr>
<td>Former athlete</td>
<td>31.4</td>
<td>30.6</td>
<td>26.8</td>
<td>46.9</td>
<td>25.8</td>
</tr>
<tr>
<td>Physician/doctor</td>
<td>70</td>
<td>82.3</td>
<td>78.6</td>
<td>84.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Physical trainer</td>
<td>58.6</td>
<td>82.3</td>
<td>64.3</td>
<td>68.6</td>
<td>21.4</td>
</tr>
<tr>
<td>Coach</td>
<td>8.6</td>
<td>12.9</td>
<td>19.6</td>
<td>25</td>
<td>15.7</td>
</tr>
<tr>
<td>Parents</td>
<td>75.7</td>
<td>54.8</td>
<td>53.6</td>
<td>71.8</td>
<td>7.1</td>
</tr>
<tr>
<td>Dietitian</td>
<td>52.9</td>
<td>67.7</td>
<td>57.1</td>
<td>68.6</td>
<td>11.4</td>
</tr>
</tbody>
</table>

B = Boxing, J = Judo, T = Taekwondo, W = Wrestling. *excludes athletes who reported never losing weight in competition experiences
RWLS’s separated by sport and sex, sport and weight division group and sport and calibre are displayed in Figure 1. No effects were found for sport, sex or weight division group on RWLS. A main effect was found for athlete calibre \( F (2,215) = 4.953, \text{MSE} = 4.757, p = 0.0079 \), with higher calibre athletes reporting the highest RWLS. No interactions were detected.
Figure 3.1 Rapid weight loss scores (RWLS) of athletes.

RWLS ±SD Separated by sport and; (A) sex, (B) calibre and (C) weight division group. Two-way ANOVA’s revealed no effect of sport, sex, or weight division group, however a significant effect of calibre on RWLS was found (p = 0.0079).

Weight loss practices prior to the current competition are displayed in Figure 2. Differences in acute/chronic weight loss preferences were significant [$\chi^2 (6, N=224) = 55.60, p <0.001$], as were methods of body water manipulation [$\chi^2 (9, N=224) = 43.34, p <0.001$], and gut
contents manipulation $\chi^2 (9, N=224) = 36.17, p < 0.001$. Over 50% of wrestlers indicated relying solely on acute weight loss compared to <30% of other athletes. Rather, these athletes tended to use a combination of acute and chronic weight loss methods. Boxers engaged in active sweating more than other athletes, whereas wrestlers were the greatest users of passive sweating. Strategies to reduce gut contents were practiced by >75% of all athletes, however most skipped meals or reduced portion sizes with only 15% of all athletes and 3% of wrestlers purposely reducing fibre intake. Furthermore ~70% of all athletes indicated they had ‘almost never’ or ‘never used’ a low fibre diet.
Figure 3.2 Present competition athlete weight loss preferences.
Athlete preferences expressed as percentage of respondents for; acute vs chronic weight loss (A), methods of body water manipulation (B), and methods of gut content manipulation (C). Athletes who did not lose weight in the month prior to present competition were excluded. Each analysis revealed significant differences (p < 0.0001).
Discussion

This is the first study to use the same measurement tools to assess weight loss practices of athletes across combat sports currently on the Summer Olympic Games program. By using a standardised research technique, based on a validated tool and sampling of athletes at significant competitions within the same country, we were able to provide a comprehensive survey of fighters in general and compare practices across sports. Most athletes practiced RWL and commonalities between sports included; the magnitudes of typical pre-competition weight loss, weight regain post-competition and the key influences on weight making practices. Of note, we identified higher calibre athletes across all sports participating in more extreme weight loss practices. Several differences existed between sports also, including; the lifetime experience of the magnitude of weight loss needed to make weight, the relative reliance on RWL and chronic weight loss to make weight, and the strategies used to manipulate gut contents and body water.

Almost all participants reported a lifetime experience of manipulating BM by substantial amounts to make weight. Indeed, the largest weight loss ranged from ~7-11% BM across sports. Although mean values are of interest in making comparisons between sports, and will be explored, the large standard deviations are concerning regarding athletes’ health, since individuals reporting BM loss of >12% were identified across all sports and included cases of >20% BM loss. Although this represents the combination of chronic and RWL, it also indicates many fighters either gain significant weight between competitive seasons and/or choose weight divisions well below training weight.

Between sports, the magnitude of the highest lifetime weight loss reported by wrestlers and taekwondo athletes was higher than judoka. While differing attitudes to weight making may exist between sports for various reasons, relatively larger intervals between weight divisions in taekwondo and wrestling compared to boxing and judo may contribute to these findings.
More athletes will find themselves at the “low end” of a wider weight division, with the perceived disadvantage of being smaller than opponents; therefore may be tempted to reduce BM to qualify for lighter weight divisions. Additionally, Olympic Taekwondo has four weight classes for both males and females, compared to eight divisions in non-Olympic competitions. Therefore, elite taekwondo athletes may cycle between two divisions according to the competition. However, this is also true for female boxers yet no differences were found between male and female boxers.

For the competitions involved in the present study, boxers favoured a more gradual approach relative to other fighters. Similarly others report amateur boxers lost 7.0% BM over three weeks prior to weigh-in, with 2.2% from RWL in the final 24h (7). This gradual approach with relatively small RWL is suited to boxing which limits the recovery time following weigh-in. However, it may not be universally practised, with evidence of boxers reducing 6% BM by dehydration over five days; similar to other combat sport athletes (123).

Inter-sport differences in weight loss methods/preferences were also found. Despite competing in fewer competitions per year, our wrestling cohort relied solely on acute weight loss more so than the other athletes; indeed more wrestlers reported using RWL alone than those using a combined acute and chronic approach. This was unexpected, as the less frequent competition calendar for Australian wrestlers theoretically provides greater opportunity for slower but real changes in BM. The favouring of RWL over chronic weight loss mirrors practices of international wrestlers who compete more frequently (20), underlining the strong cultural component within wrestling.

Although sweating was utilised to achieve RWL across all sports, differences existed in preference for passive or active methods. For example; ~90% of boxers utilised active sweating compared to ~70% of taekwondo and wrestling athletes. This makes sense given the physiological responses to passive versus active sweating and boxing weigh-in regulations.
i.e. passive sweating decreases plasma volume, sweat rate and stroke volume during exercise, thereby increasing heart rate and heat storage - all of which occur less following active sweating (96). Thus with limited recovery time following weigh-in, boxers would be less compromised following active sweating. Whereas in the other sports; greater recovery times increases opportunities for passive sweating whilst maintaining competitive performance.

Most athletes reduced food intake concurrent to RWL, with skipping meals and/or a reduction in portion sizes being common. Both approaches reduce energy intake (aiding chronic BM loss) and reduce gut contents towards RWL goals. However, severe dietary restriction may impair performance via muscle mass loss and reduced muscle glycogen needed to fuel competition (23). Few athletes reported intentionally/strategically reducing gut contents through decreased dietary fibre intake (79). Decreased fibre intake and food weight may be the least compromising RWL method; achieving BM loss without interfering with competition nutrition goals (113). Therefore, education to all fighters is warranted.

Although infrequently reported here, the harmful practices of vomiting, and use of banned diuretics or laxatives remain concerning and should be actively discouraged. Our findings are roughly in line with international data on the reported use of diuretics and laxatives (20-22). Of particular interest was the emerging use of ‘water loading’ used by approximately half of the surveyed athletes at some time. This practice is appears popular in professional combat sports (91) with athletes suggesting excessive water intake over several days promotes polyuria which persists acutely following fluid restriction. The efficacy of this practices remains to be confirmed clinically (91), however suppression of vasopressin has been noted following three days of a water loading protocol similar to those used by combat sport athletes (124, 125). Given the apparent popularity of this technique and the potentially dangerous outcomes of hyponatremia (86), investigation is warranted.
Although we identified differences in practices between sports, many commonalities existed. Athletes report similar magnitudes of BM gain following competition and during the off-season, and thus a similar weight loss target prior to competition. Combat sport athletes experience a common pressure to manipulate BM to meet deadlines, and to cycle between restrictive eating behaviours and excessive exercise to overeating, particularly immediately after competitions (22). Indeed, fighters who are self-reported as ‘weight cyclers’ experience higher rates of obesity in later life (126). Body image issues (127), anxiety and eating disorders are common among all Olympic combat sports (22, 44, 117).

Contrasting earlier research (52, 128); neither sex or weight division group had an effect on RWLS. This may be because the RWLS is a measure of historic practices and athletes may have changed weight divisions over the course of their career. The finding that RWLS is linked to athlete calibre across all sports is interesting. Several explanations are possible. First, aggressive RWL practices may provide an advantage and those able to sustain these practices achieve greater success. Alternatively, RWL may not be beneficial; yet greater training time and exposure to quality training environments may improve competitive performance concurrent to exposure to RWL practices; increasing the likelihood of their adoption. Indeed a key finding in our study was across all sports, other athletes and coaches were identified as key influences on athletes’ practices. Therefore it is possible; increased training time, starting from a younger age, leads both to competitive success and exposure to RWL practices from coaches and other athletes. Furthermore, successful athletes often become coaches, thus reinforcing RWL in subsequent generations. However, we recognise other studies implemented the RWLQ have reported contrary results regarding RWLS and competition level (17, 21). Therefore, a clear understanding of this relationship warrants further exploration.
Limitations of this study include; 1- the fact we were unable to have every competitor at the competitions complete the survey, thus the non-responders may have biased our results, and 2- the reliance on self-reported data.
Practical applications

Reviews of optimal approaches to RWL and recovery in weight category sports are available (73, 113), yet there is room for additional sport-specific recommendations tailored to specific situations. Those devising such recommendations should provide guidelines aimed at optimising physiology, health and performance appropriate to each sport in a context relevant and relatable to competitors, taking into consideration the existing practices of these athletes (e.g. wrestlers may require additional education regarding their reliance on RWL and passive dehydration, and help in identifying an ideal weight division relative to other athletes). Despite interventions discouraging RWL, the practice remains common. Additionally, new techniques are emerging which if taken to the extreme may have adverse health implications. Overcoming ingrained cultural practices may be difficult, however support staff may improve the uptake of their advice by targeting coaches and identifying key athletes within gyms/social networks as these are the key influencers on athlete behaviour and appear is a common feature among all Olympic combat sports. The issue of RWL in combat sports is likely to continue to be a contentious issue, indeed some have likened RWL to doping and called for the complete abolition of the practice (33). Regulations which have shown promise in reducing RWL include the removal of the recovery period post weigh-in and hydration testing at weigh-in (129), however implementing these changes worldwide in order to impact Olympic combat sport athletes of all levels would seem extremely difficult. Until such time regulations specifically and systematically prohibit the practice it appears athletes will continue to engage in RWL, thus sports nutrition professionals will need to pragmatically balance athletes’ desires to achieve (real or perceived) advantages with concerns for their physical, mental and emotional safety.
Our study provides value in collecting robust information on RWL practices of combat athletes as well as demonstrating a research approach that could be applied across other weight category sports.
Conclusions

The majority of Olympic combat sport athletes in Australia utilise RWL in order to make weight for competition. Multiple similarities in weight loss experiences and practices exist across combat sports including the magnitude of shifts in BM before and after competition, yet there are some differences independent of the wider culture of weight making behaviour. Greater competitive success, or at least the practices of the more successful athletes, is associated with more extreme RWL practices. Sports nutrition professionals should familiarise themselves with the nuances that exists within and between combat sports, to better develop context specific strategies for chronic BM management, RWL and recovery around competition, using the influence of coaches and top athletes to spread information on better practices.
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“Regain in body mass after weigh-in is linked to success in real life Judo competition”

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Abstract

We examined the relationship between the re-gain of body mass (BM) after weigh-in and success in real-life judo competition. Eighty-six (36♀/50♂) senior judoka volunteered for this observational study of an international judo competition. Subjects were weighed at the official weigh-in and one hour before their first competition fight (15-20 hours later). Regain in BM after weigh-in was compared between medal winners and non-medallists, winners and losers of each fight, males and females and across weight divisions. Heavyweights were excluded from analysis. Pre-fight BM was greater than BM at official weigh-in for both males and females, with % BM gains of 2.3±2.0 (p=<0.0001; ES= 1.59; CI95% [1.63, 2.98]) and 3.1±2.2 (p=<0.0001; ES=2.03; CI95% [2.30, 3.89]), respectively. No significant differences were found between weight divisions for post weigh-in BM re-gain. Differences in post weigh-in BM re-gain were significantly higher in medal winners than non-medallists for males and females combined (1.4±0.4% BM; p=0.0026; ES= 0.69; CI95% [0.05, 2.34]) and for males alone (1.5±0.6% BM; p=0.017; ES= 0.74; CI95% [0.02, 2.64]), but not for females (1.2±0.7% BM; p=0.096; ES=0.58; CI95% [-0.02, 2.31]). Differences in BM re-gain after weigh-in between winners and losers were significant across all fights (0.9±0.3% BM; p=0.0021; ES= 0.43; CI95% [0.31, 1.41]) but not for first round fights (0.8±0.5% BM; p=0.1386, ES=0.38; CI95% [-0.26, 1.86]). Winners showed a greater re-gain in BM post weigh-in than losers. This may reflect the greater magnitude of the BM loss needed to achieve weigh-in targets which also relates to the experience level of successful athletes.
Introduction

Combat sports typically separate athletes into weight divisions in an attempt to create an ‘even playing field’ for size-matched opponents. An official weigh-in is held before competition to ensure each athlete’s weight is within the lower and upper limits of the weight division they contest for. However, the majority of combat sport athletes appear to undertake rapid weight loss practices before weigh-in (15, 16, 93), with average losses equivalent to ~5% body mass (BM) being commonly reported however ranges vary between and within different combat sports (13, 15, 20, 21). Acute “weight making” strategies, which predominantly reduce BM via losses of fluid (23), are used to provide the athlete with the theoretical benefit of fighting in a division that is lower than their habitual BM against smaller/lighter competitors; thus gaining a potential size and/or leverage advantage. This practice occurs in spite of warnings by health professionals (130), as well as evidence that rapid weight loss of even 2% BM can cause an impairment in aerobic performance (23) with greater BM loss affecting anaerobic performance measures relevant to combat sport athletes (5, 8, 114). The persistence of weight making may be due to the transient nature of negative performance effects and/or ingrained practices in combat sport culture (131). Indeed, many combat sport athletes believe rapid weight loss is an integral part of their sport (44) and there are circumstances within combat sports that support or at least tolerate the involvement of such practices.

First, in combat sports, an athlete’s performance is measured relative to their opponent in an open environment. Therefore combat sport athletes don’t have to perform at their physiological best to win; they simply have to perform better than their opponents. The second factor favouring these practices is the period between the official weigh-in and the start of competition which creates an opportunity for athletes to ingest foods and fluids to restore hydration and fuel status, attenuating the negative effects of rapid weight loss (16,
In the sport of judo, the time between the official weigh-in and the start of the competition may be up to 20 hours, supporting the opportunity for severe weight loss practices. Recent rule changes in judo have tried to limit extreme weight making by stating athletes are not allowed to weigh more than 5% above their weight division at the time of random weight checks conducted the morning of competition.

It is of interest to investigate actual weight making practices of athletes in specific combat sports to document the magnitude of BM losses and factors that support the continuation of a “weight making culture”. However, the logistics of monitoring acute weight loss are difficult (athletes typically arrive only hours before weigh-in) and are likely to interfere with real-life choices. Additionally, chronic weight loss methods (e.g. body fat loss) overlap with acute weight loss strategies making them difficult to separate. Nevertheless, in studies of wrestling and taekwondo, the re-gain in BM between the official weigh-in and start of competition has been used as a surrogate measure of the magnitude of the acute weight loss needed to achieve a weigh-in target (48, 52).

To date, few studies have examined the relationship between post weigh-in weight re-gain and competitive success and none in Judo. Given the different physiological demands of judo (132), its popularity worldwide and its prominence at the summer Olympic games (offering 56 medals), advancing empirical knowledge of this specific sport is valuable.

Accordingly, the aim of the present study was to measure the re-gain of BM between the official weigh-in and the first match (“Post weigh-in BM re-gain”) in a judo competition and examining its relationship to competitive success (chances of winning fights and medalling) among judo players as a whole and their various sub-groups.
Methods

This study investigated the relationship between post official weigh-in BM re-gain and competition success at an international judo competition. Males (n=50) and females (n=36) in the senior categories of the Australian Capital Territory International Judo Open (Judo Federation Australia) volunteered to participate in this study, providing written informed consent. The study was approved by the higher research ethics committee at the University of Sunshine Coast, Queensland, Australia.

The competition took place over three days, involving two official weigh-in processes and two days of competition across the various weight divisions. The first weigh-in took place in the afternoon of day one for those competing on day two and the second weigh-in took place in the afternoon of day two for those competing on day three. All athletes were required to weigh-in between 5-7pm the evening before competition. Competition started from 10am on each competition day and finished before 6pm.

Researchers collected BM measurements of judoka pre warm-up, one hour before their first fight, which represented a period of 15 to 20 hours from the official weigh-in. Both the first (official weigh-in) and the second (pre-fight) BM measurements were undertaken on the same scales (Tanita, Japan, BWB800S). Where possible judoka were weighed in the same clothing. In situations where this was not possible details of clothing were noted and later weighed separately to account for these differences.

Descriptive statistics have been used to report the change in BM from official weigh-in to competition in terms of absolute values (kg) and percentage BM. Further analyses were completed according to sex, weight division and competition success. A repeated measures two-way analysis of variance (ANOVA) with Bonferroni post-hoc tests was used to compare official weigh-in BM and pre-fight BM between males and females. For between-subject comparisons, Levene’s test of homogeneity was conducted followed by unpaired t-tests when
single comparisons were made (i.e. between medallists and non-medallists; between winners and losers) and by one-way ANOVA with a Bonferroni post-hoc test when multiple comparisons were made (between weight divisions). In recognition of the multiple sampling of this data set, a Bonferroni correction was applied to all t-test findings, by reducing the level of significance to P<0.0125. Additionally, 95% confidence intervals (CI95%) and Cohen d effect sizes (ES) have been reported when appropriate. The magnitudes of these ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen (133). All data are reported as mean ± SD. No male heavyweights (>100kg division) were included in the analysis since weight making is not required for this division. Analysis was completed using PRISM v 6.0 (GraphPad Software, San Diego, California, USA).

Results
Eighty-six of 110 athletes who competed in the tournament participated in the study. This sample included 44 of 45 medal winners across the 12 weight divisions examined. Four medals (one gold, one silver and two bronze) were awarded for each division with the exception of the male <100kg and female <78kg divisions in which only three and two athletes competed respectively. A two ANOVA with Bonferroni post hoc comparisons tested the BM change of judo athletes from weigh-in to pre-fight amongst males and females (Table 4.1). A significant effect was found for sex, F (1, 84) = 34.28, p = < 0.0001, and time F (1, 84) = 136.2, p = <0.0001; there was no significant interaction between time and sex F (1, 84) = 0.2041, p = 0.6526.

Pre-fight BM was significantly greater than weigh-in BM for both males and females with mean BM gains of 2.3% BM (p=<0.0001; ES= 1.59; CI95% [1.63, 2.98]) and 3.1% BM (p=<0.0001; ES=2.03; CI95% [2.30, 3.89]), respectively. No significant differences were
found between males and females in post weigh-in BM re-gain with either absolute BM or percentage BM (Table 4.1).

<table>
<thead>
<tr>
<th>Table 4.1 Weigh-in and pre-fight body mass by sex (mean ±SD)</th>
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<tr>
<td></td>
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<tr>
<td>----------------</td>
</tr>
<tr>
<td>n=</td>
</tr>
<tr>
<td>Weigh-in BM (kg)</td>
</tr>
<tr>
<td>Pre-fight BM (kg)</td>
</tr>
<tr>
<td>BM change (kg)</td>
</tr>
<tr>
<td>BM change (%)</td>
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</table>

* Denotes significant difference from weigh-in BM

Mean changes in percentage BM by weight divisions are displayed in Figure 1. There were no significant differences between weight divisions for either males (F (5, 41) = 0.5732, p = 0.72), or females (F (5, 30) = 1.016, p = 0.4258). Medium and large effect sizes were found between many of the divisions. The number of females gaining more than 5% BM was 1, 2, 1, 0, 2, and 0 for the under 48kg, 52kg, 57kg, 63kg, 70kg and 78kg divisions, respectively. For males this was 3, 2, 3, 1, 0, and 0 for the under 60kg, 66kg, 73kg, 81kg, 90kg and 100kg divisions, respectively. This accounts for 17.4% of all athletes, and 25% of all medal winners.
Figure 4.1 Post weigh-in weight re-gain between weight divisions.
Weight re-gain expressed as percentage of body mass for females (A) and males (B). Analysis of variance revealed no significant differences between weight divisions.

When separated into medallists and non-medallists, significant differences in percentage BM re-gain were evident for males and females combined at 1.4±0.5% BM (p=0.0026; ES= 0.69; CI95% [0.05, 2.34]) and for males alone at 1.5±0.6% BM (p=0.017; ES= 0.74; CI95% [0.02,
Differences between medallists and non-medallists were not significant for females at 1.2±0.7% BM (p=0.096; ES=0.58; CI95% [-0.02, 2.31]) (Figure 2).

Figure 4.2 Post weigh-in weight re-gain between medal winners and non-medallists. Weight re-gain expressed as percentage of body mass for; females (A); males (B); and all competitors (C). Unpaired t-tests revealed significant differences for all competitors and for males, but not for females. (* p = 0.017, ** p = 0.0026).
Percentage BM re-gain of winners and losers of bouts are displayed in Figure 3. Results were analysed for all fights during the competition, as well as first round fights only. As BM was measured before the first fight we can only be truly confident in BM discrepancies between winners and losers in this round, as BM may have changed between the first and subsequent rounds. When the first round fights were analysed the fighter who re-gained the most BM won in 65.6% of the fights, the fighter who regained the least BM won in 31.3% of the fights and in 3.1% of the fights both fighters regained the same BM. However, differences in BM changes of $0.8 \pm 0.5\%$ BM were not significant between winners and losers ($p=0.1386$, $ES=0.38$; CI95% [-0.26, 1.86]). When all fights were grouped together differences in BM change of $0.8 \pm 0.3\%$ BM were found to be significant ($p=0.0021$; $ES=0.43$; CI95% [0.31, 1.41]). The fighter who re-gained the most BM won in 59.6% of the fights, the fighter who re-gained the least BM won in 39.4% of the fights and in 1.0% of the fights both fighters regained the same BM.
Figure 4.3 Post weigh-in weight re-gain between winners and losers. Weight re-gain expressed as percentage of body mass for; first round fights only (A) and all fights (B). Unpaired t-tests revealed significant differences when all fights were analysed, but not in first round fights. (** p = 0.0021).

Discussion

This is the first study to examine the relationship between the re-gain in BM between official weigh-in and competition in judo athletes and competitive success. As expected, fighters gained a significant amount of BM between the official weigh-in and their first fight. Of note,
differences in the magnitude of BM gain were found between medallists and non-medallists, particularly for males, and between winners and losers when comparing results across all fights. Significance was not reached when analysing only female bouts or when analysing only first round fights, although this may have been the case given a larger sample size, as similar patterns and effect sizes were evident. Specifically, the more successful athletes recorded the greatest amount of weight re-gain compared with their less successful counterparts. On the basis that weight re-gain is a surrogate measure for the magnitude of BM loss before the official weigh-in, our findings suggest that successful judoka undertake more severe rapid weight loss practices and/or that more severe rapid weight loss practices provide fighters with a weight advantage which is associated with success in judo.

The findings of this study are in agreement with existing literature on weight category sports which reports that athletes compete at a BM that is significantly heavier than their official weigh-in BM (48, 52). When interpreted in the context of previous (self-reported) data (15, 16, 21), our results confirm that judoka undertake rapid weight loss before weigh-in, then attempt to reverse this loss before competition. In contrast to previous studies (48, 52), we failed to detect differences in the magnitude of BM re-gain between males and females, or across weight divisions. However different patterns of practice with medium and large effect sizes were evident across weight divisions.

The findings of this study suggest a relationship exists between post weigh-in BM re-gain and competition success. Significant differences in BM re-gain were observed between medallists and non-medallists, and between winners and losers of each fight. These clear findings are in contrast to mixed results from the literature on competition practices of wrestlers and taekwondo athletes (46, 48, 52). Previous studies have reported a competition advantage for athletes who re-gain the most BM among high school wrestlers (46), but not in higher level collegiate wrestlers (52). It is acknowledged that success in combat sports such
as judo and wrestling is determined by multiple factors including aerobic and anaerobic fitness, strength, power, psychological and emotional state and perhaps most importantly skill and technical proficiency (8, 134). Among high school athletes, where many of these areas are not well developed, BM, power and strength may contribute more to an athlete’s overall attributes than in more experienced athletes. Furthermore, in the case of the study of elite collegiate wrestlers, which took place at the national championships of a highly selective competition, it is likely that this cohort consisted of a more homogenous group of already successful athletes. Indeed, in this study, the post-weigh increases in BM reported for winners and losers were substantially higher (5.3±2.0% vs 5.3±2.4% respectively), than that reported in the study of high school wrestlers (2.4±1.8% vs 1.9±1.6%). Such differences are in line with previous research suggesting higher calibre elite athletes engage in greater levels of rapid weight loss (and thus likely BM re-gain after weigh-in) than their junior counterparts (8, 15, 16, 21).

While our study extended the investigation of the relationship between post weigh-in BM re-gain and success to a sport not previously examined, we note also that the rules of judo competition allow a subtle but important difference in determination of success to be included into this body of research. While examining the outcome of individual fights provides one measure of success, many fights are decided by a judge’s decision and although judges are trained and experienced, they are not infallible. Indeed, the subjectivity of the referees’ decisions, a fighters’ individual tactics and the random nature of the competition draw in elimination tournaments introduces statistical noise into the interpretation of ‘competitive success’. However, since judo utilises a repechage system which allows fighters who lose to gold medallists in the early rounds to be reintroduced into competition, examination of the results of the entire competition (i.e. who wins a medal and who does not)
provides a less noisy model of competition success and thus enables stronger conclusions to be made.

Although the event involved in the present study was a high level competition involving experienced competitors and allowing international entrants, the lack of a qualification requirement allowed the attendance of athletes of lower calibre and experience. Therefore, although our results confirm a difference in weight making practices according to the success of the athletes, a limitation is that we cannot establish a cause and effect relationship. Indeed, it is likely that winners of individual fights and medallists were more successful in both their competitive skills and their ability to manipulate BM to reach a weight division goal than their less successful counterparts. Self-selection bias may mean that skilled combat sport athletes who are unable to manage weight making practices may drop out of the sport. While not in use at the present competition, the rule which enforces random weight checks the morning of competition forbidding athletes re-gaining more than 5% BM following weigh-in may have affected the results of our study if enforced. When this rule is enacted; athletes have the opportunity to reduce their BM to within the 5% limit avoiding disqualification. To account for this hypothetical situation, we re-analysed the data reducing BM re-gain values which were greater than 5%, to 5%. Whilst p values, means and standard deviations changed slightly, all of the previous significant findings remained. Similarly, as the male <100kg division and female <78kg divisions only contained three and two competitors respectively, all were awarded medals and this may have effected statistical significance. Thus we reanalysed the data omitting these values and again the significant findings remained.

**Novelty statement**

This study is the first to measure post official weigh-in BM re-gain in judo athletes in real-life competition. While the present findings cannot confirm that the magnitude of the re-gain in
BM after official weigh-in is causative of success in judo, clear differences were revealed between successful and non-successful athletes, in terms of the outcome of individual fights and overall competition success.

**Practical application**

Elite judo athletes engage in acute BM loss practices before official weigh-in and re-gain a substantial amount of BM prior to fighting. Physiologists and sports nutrition professionals should work with coaches and athletes to devise optimal methods of BM manipulation which minimise any performance decrements, while ensuring the health and wellbeing of the athlete. Additionally strategies may need to be developed to help judo athletes adhere to the rule governing random BM checks on the morning of competition which prohibit a BM gain above 5% of an athlete’s weight division.
Acknowledgments, authorships, declarations of funding sources and conflicts of interest

The authors would like to acknowledge the support and cooperation of Judo Federation Australia and the individual athletes in conducting this study.

The study was designed by Reid Reale (RR), Gary Slater (GS), Louise Burke (LB) and Gregory Cox (GC); data were collected and analysed by RR and LB; data interpretation and manuscript preparation were undertaken by RR, GC and LB. All authors approved the final version of the paper.

This study did not receive any funding.

All the authors declare that they have no conflict of interest derived from the outcomes of this study.
Chapter 5
STUDY THREE

Published as original investigation in
International Journal of Sport Physiology and Performance:

“Weight re-gain is not linked to success in a real life multi-day boxing tournament”

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2 University of Sunshine Coast, Sippy Downs, Queensland, Australia
3 Australian Catholic University, Melbourne, Victoria, Australia
Abstract

**Purpose:** Combat sport athletes acutely reduce body mass (BM) prior to weigh-in in an attempt to gain a size/strength advantage over smaller opponents. Few studies have investigated these practices among boxers and none have explored the impact of this practice on competitive success. **Methods:** One hundred (30♀/70♂) elite boxers participating in the Australian National Championships were weighed at the official weigh-in and an hour before each competition bout. Re-gain in BM after weigh-in was compared between finalists and non-finalists, winners and losers of each fight, males and females and weight divisions. Boxers were surveyed on their pre and post weigh-in nutrition practices. **Results:** The lightest male weight category displayed significantly greater relative BM re-gain than all other divisions, with no difference between other divisions. BM pre-bout was higher than official weigh-in for males (2.12±1.62% (p < 0.001; ES=0.13)) and females (1.49±1.65% (p < 0.001; ES=0.11)). No differences in BM re-gain were found between finalists and non-finalists, winners and losers of individual bouts, or between preliminary or final bouts. BM re-gain was significantly greater (0.37% BM, p < 0.001; ES=0.25) prior to an afternoon bout compared to a morning bout. **Conclusions:** Boxers engage in acute BM loss practices before the official competition weigh-in but this does not appear to affect competition outcomes, at least when weight re-gain between weigh-in and fighting is used as a proxy for the magnitude of acute loss. While boxers recognise the importance of recovering after weigh-in, current practice is not aligned with best practice guidance.
Introduction

Weight divisions in combat sports exist in order to have athletes matched against those of similar size. An official weigh-in is held before the start of competition to ensure that competitors are within the weight requirements for their division. It is commonplace for athletes to utilise ‘weight making strategies’ to induce rapid weight loss (RWL) before the official weigh-in(7, 15, 16, 93). These strategies, primarily decreasing body mass (BM) via losses of body water, are commonly utilised by athletes to qualify for a lighter weight division, gaining a potential size and/or leverage advantage(16) over smaller opponents. Average weight losses equivalent to ~5% BM in the hours and days before the official weigh-in are reported, however ranges vary between and within different combat sports(13, 15, 20, 21).

Combat sport athletes induce RWL despite warnings by medical professionals(130), as well as evidence that RWL impairs performance, at least when measured directly after the weight-making strategy(23). Why athletes continue to engage in practices that induce RWL may in part be due to the long standing culture evident in combat sports(131). Indeed, the majority of these athletes perceive RWL as a fundamental part of their sport(44). Importantly, a competitor’s success is not dependent on absolute performance, rather on their performance relative to their opponents’ in an open environment. Thus it is not necessary to perform at one’s physiological best to win, but rather to outperform one’s opponent.

The recovery period between the official weigh-in and competition creates an opportunity for athletes to ingest foods and fluids to restore hydration and fuel status, attenuating the negative effects of RWL(16, 71). The temptation for undertaking RWL increases when the recovery period is extended since it theoretically provides more opportunity to reverse the deleterious effects of RWL. Rules governing the timing of the official weigh-in and start of competition vary among combat sports. Olympic boxing competition is unique in that athletes are
required to weigh-in the morning of the first day of competition and then each subsequent
day they compete throughout the competition (135). This leaves limited time to recover from
RWL before the start of competition each day of the event. Reports of commonly used weight
loss practices and their effects on various aspects of physiology appear in the literature which
are derived from surveys and laboratory studies respectively (49, 115, 120, 123, 136, 137).
Despite this, there is little data measuring actual weight loss in boxers, particularly those
engaged in multi-day competitions.

Although it is of interest to monitor the real-life RWL practices of combat sport athletes and
investigate their effect on performance or competitive success, there are inherent difficulties
in undertaking such work (e.g. athletes typically arrive at the competition only hours before
the official weigh-in). Additionally, chronic weight loss strategies (e.g. reducing fat mass)
coincide with RWL making them impossible to separate. However, the re-gain in BM
between the official weigh-in and the start of competition (the recovery period) can generally
be monitored, and has been used as a surrogate measure of the magnitude of the RWL
incurred to achieve a weigh-in target (48, 52) at least when the recovery period is sufficiently
lengthy to allow eating/drinking practices to be freely chosen.

Aside from gaining an understanding of RWL incurred before competition, examining BM
re-gain post official weigh-in during competition affords an exploration of its association
with competitive success (46, 48, 52, 138). Several studies have examined the relationship
between competition success and BM re-gain in grapplers suggesting a potential benefit for
those gaining more weight post weigh-in, although this may be affected by the competition
level of the athlete (46, 52, 138). One study investigated this relationship in striking athletes
(taekwondo competitors) and found no correlation (48). It is important not to simply infer that
what is true in judo, wrestling and taekwondo holds true for boxing, as these sports are truly
unique and require different physiological and anthropometric attributes from athletes (8,
To-date, no investigations have examined this relationship in boxing. In addition to vastly different physical requirements, amateur boxing offers another unique characteristic; requiring weight making over successive days with a more limited timeframe for recovery than other combat sports.

Accordingly, the primary aim of the present study was to measure boxers’ BM re-gain between the official weigh-in and each bout (“Post weigh-in BM re-gain”) in a multi-day competition, and examine its relationship to competitive success. Additionally, we investigated whether the need to repeatedly make weight affects the degree of BM re-gain; and whether an extended recovery time affects BM re-gain. Lastly, we collected information on boxers’ RWL and post weigh-in recovery practices.
Methods

Males and females in the elite categories of the 2015 Australian National Amateur Boxing Championship (Boxing Australia) volunteered for this project. We implemented an observational approach to examine weight fluctuations throughout a tournament and its relationship to competition success. The study was approved by the higher research ethics committee at the University of Sunshine Coast, Queensland, Australia and participants provided informed consent.

The event took place over six days (Day 1: Initial weigh in and Days 2-6: competition) with official weigh-ins being held every morning. The initial weigh-in took place 0730-0900 in the morning of Day 1 for all competitors. Subsequent weigh-ins took place each morning at 0630-0700 only for boxers competing that day. Two competition sessions were undertaken each day; a morning session, 1000-1500; and an afternoon session, 1600-2100.

In addition to the official weigh-in BM; we recorded BM of boxers within an hour of their bout. Hence a minimum of three hours and a maximum of approximately 12 hours elapsed between the official weigh-in and the pre-bout weigh-in. Elapsed time depended on whether a boxer fought in the morning or afternoon session, and the fight schedule. Body mass measurement was conducted using the same set of scales used during the official weigh-in (Tanita, Japan, BWB800S). Where possible, boxers were weighed in the same clothing as the official weigh-in. In situations where this was not possible, details of clothing were noted and weighed separately to account for differences.

Before leaving the competition, boxers were asked to complete a survey assessing their post weigh-in nutrition behaviours as well as their weight loss practices in the seven days before competition. The survey was based on previous work from our group examining post weigh-in recovery practices in light weight rowers (19), tested for content validity and screened for readability and comprehension by relevant experts (Australian Institute of Sport (AIS))
dietitians) and comparable athletes to those who completed the survey in present study (combat sport athletes training at the AIS). The survey included both closed and open ended questions relating to fluid and food choices, as well as factors influencing their nutrition practices. Questions examining pre weigh-in RWL focused on strategies which affect muscle glycogen content, total body water status and gut contents as these are the BM compartments that can be acutely manipulated\cite{16, 23, 79, 113, 139}. Boxers were asked to indicate (yes/no) to a range of factors that influenced their post-weigh in nutrition practices and then rate the importance of that factor using a 1-5 Likert scale.

In this study we report descriptive statistics of the survey data. Chi square tests were performed to determine if survey responses differed from chance and to report on differences between responses where appropriate. Descriptive statistics were used to report mean change in BM from weigh-in to competition in absolute values (kg) and percentage of BM with further analyses completed according to sex, weight division group (multiple weight divisions were grouped together in order to provide sufficient sample sizes for ANOVA analysis) and competition success. A repeated measures two-way ANOVA with Bonferroni post-hoc tests was used to compare official weigh-in BM and pre-fight BM between males and females. For within-subject single comparison questions paired t-tests were conducted. For between-subject comparisons, Levene’s tests of homogeneity were conducted followed by unpaired t-tests when single comparisons were made and by ANOVA with a Bonferroni post-hoc test when multiple comparisons were made. Boxers were separated into finalists and non-finalists to determine the relationship between BM re-gain and success. The two boxers who qualified for the final bout were considered finalists, except in the case of divisions with only two competitors where only the winner was counted as a finalist. In recognition of the multiple sampling of this data set, a Bonferroni correction was applied to all findings, by reducing the level of significance to P<0.0125. Additionally, 95% confidence intervals (CI95%) and
Cohen d effect sizes (ES) are reported when appropriate. The magnitudes of these ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen (4). All data is expressed as mean ±SD. No male super heavyweights (>91kg division) were included in the analysis as they are not required to make weight.

### Results

One hundred of the 101 boxers who competed in the tournament participated in the study, including all winners. One boxer failed to make weight which occurred on the morning of the first competition day. In total, 85 bouts were included in the analysis.

Table 5.1 presents BM data measured at weigh-in and pre-bout. There was a significant effect for sex, $F (1, 98) = 16.91$, $p < 0.001$, and time $F (1, 98) = 110.1$, $p < 0.001$; as well as for the interaction between time and sex, $F (1, 98) = 6.532$, $p = 0.0121$. Across all bouts, pre-fight BM was significantly greater than official weigh-in BM for both males ($p < 0.001$; ES= 0.13; CI95% [1.10, 1.62]) and females ($p < 0.001$; ES=0.11; CI95% [0.43, 1.22]) (Table 5.1).

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
<th>Combined</th>
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<tr>
<td><strong>n =</strong></td>
<td>70 (70%)</td>
<td>30 (30%)</td>
<td>100</td>
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<tr>
<td><strong>Weigh-in BM</strong></td>
<td>66.99±10.4kg</td>
<td>58.66±7.6kg*</td>
<td>64.49±10.35kg</td>
</tr>
<tr>
<td><strong>Pre-bout BM</strong></td>
<td>68.35±10.28kg</td>
<td>59.49±7.4kg*</td>
<td>65.70±10.32kg</td>
</tr>
<tr>
<td><strong>BM re-gain (Kg)</strong></td>
<td>1.36±0.97kg</td>
<td>0.82±0.9kg*</td>
<td>1.2±0.98kg</td>
</tr>
<tr>
<td><strong>BM re-gain (%)</strong></td>
<td>2.1±1.6%</td>
<td>1.59±1.6%*</td>
<td>1.9±1.6%</td>
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</tbody>
</table>

* Denotes significant difference from males

Percent changes in BM re-gain by weight division group are presented in Figure 1. No significant differences were found between weight division groups for females ($F (3, 26) = 2.154$, $p = 0.948$), however significant differences existed between male weight division groups ($F (3, 66) = 3.22$, $p = 0.028$). Weight re-gain was significantly greater in the lightest
weight division group (<49kg, <51kg, <56kg) than in the heaviest weight division group (<81kg, <91kg).

Figure 5.1 Body mass re-gain between weight division groups.

Body mass re-gain expressed as percentage of body mass for; males (A) and females (B). Analysis of variance revealed no significant differences between weight divisions for females. A significant difference between the lightest and heaviest weight division groups in males was revealed (*).
Differences in BM re-gain for boxers who competed in the morning and afternoon sessions and for those who competed in preliminary and final bouts are displayed in Figure 2. BM re-gain was greater (0.37% BM, $p < 0.001$; ES=0.25; CI95% [0.12, 0.61]) for afternoon bouts compared to morning bouts. Body mass re-gain was not different between preliminary and final bouts (0.25% BM, $p = 0.129$; ES=0.18; CI95% [-0.08, 0.59]).
Figure 5.2 Body mass re-gain comparisons between morning and afternoon, and preliminary and final bouts.

Body mass regain expressed as percentage of body mass for boxers who competed in both; (A) morning and afternoon bouts (n=25) and (B) preliminary and final bouts (n=26). Paired t-tests revealed significant differences in BM re-gain between morning and afternoon bouts (** p = 0.0051) but not for preliminary and final bouts.

In forty-one of the eighty-five bouts analysed the winner was heavier than the loser. In forty bouts, the loser was heavier than the winner; on three occasions both boxers were the same.
weight and one bout was not analysed due to incomplete data. Percentage BM re-gain for finalists and non-finalists are presented in Figure 3. No significant differences in BM re-gain were found between finalists and non-finalists among males 0.13% BM (p = 0.771; ES=0.08; CI95% [-0.77, 1.03]); females 0.68% BM (p = 0.266; ES=0.41; CI95% [-1.91, 0.54]); or males and females combined, 0.02% BM (p = 0.948; ES=0.01; CI95% [-0.67, 0.71]).
Figure 5.3 Body mass re-gain comparisons between finalists and non-finalists.

Body mass regain expressed as percentage of body mass for; males (A), females (B) and combined males and females (C). Unpaired t-tests revealed no significant differences in BM re-gain between finalists and non-finalists.

BM fluctuations throughout competition for females, males, and females and males combined; and, for those who competed in the maximum four bouts possible (males only) are displayed in Figure 4. These results mirrored the general findings that BM measurements for
bouts were greater than weigh-in measurements and that males displayed greater BM re-gain than females. There were no significant differences in fluctuations across the course of the tournament.

**Figure 5.4 Body mass re-gain between weigh-ins and bouts throughout tournament.**
Body mass regain expressed as percentage of body mass for; females (A), males (B), males and females combined (C) and males who competed in bouts in all four rounds (D). No significant differences in BM re-gain between bouts were found.
Seventy-three of 101 athletes completed the survey on pre and post weigh-in weight loss and nutrition practices. Respondent’s weight loss strategies used in the week before the current competition are displayed in Table 5.2. Respondents self-reported losing 3.6% BM in the week before competition (3.5% BM for females and 3.7% BM for males). The most popular methods of weight loss were active dehydration and a reduction in food portion sizes.

<table>
<thead>
<tr>
<th>Table 5.2 Self-reported acute weight loss methods prior to weigh-in</th>
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<tbody>
<tr>
<td><strong>Active dehydration</strong></td>
</tr>
<tr>
<td>Fluid manipulation</td>
</tr>
<tr>
<td>Reduce portion sizes/ skip meals</td>
</tr>
<tr>
<td>Gut content manipulation</td>
</tr>
<tr>
<td>Reduce carbohydrate intake</td>
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<tr>
<td>Energy / carbohydrate manipulation</td>
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</table>

Chi square analysis determined reported frequencies to responses for each question were significantly different to chance (p < 0.01)

A majority (81%) of respondents reported following a plan during the post weigh-in recovery period with the remainder indicating the absence of a plan. Factors influencing post-weigh-in nutrient intake are presented in Figure 5, together with mean ratings of how important they were to the survey respondents. Significant differences existed between influencing factors (F (6, 497) = 75.53, p < 0.001).
Figure 5.5 Factors influencing post weigh-in dietary intake
Expressed as boxers’ mean ratings (0-5) of the importance of various factors when considering food and fluid intake practices post weigh-in/ prior to a bout. ANOVA revealed significant differences exist between factors (p < 0.001).

Post weigh in food and fluid intake are presented in tables 5.3 and 5.4 respectively. Only one respondent indicated not consuming any foods or snacks other than fluids.

Table 5.3 Athlete post weigh-in food intake practices

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Sometimes</th>
<th>Never</th>
</tr>
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<tbody>
<tr>
<td>Consumes foods or snacks other than fluid</td>
<td>83%</td>
<td>16%</td>
<td>1%</td>
</tr>
<tr>
<td>Prepares own meals and snacks</td>
<td>42%</td>
<td>50%</td>
<td>8%</td>
</tr>
<tr>
<td>Utilises pre-packaged meals or snacks</td>
<td>8%</td>
<td>73%</td>
<td>19%</td>
</tr>
<tr>
<td>Purposely consumes high salt foods or adds salt to food</td>
<td>6%</td>
<td>40%</td>
<td>54%</td>
</tr>
<tr>
<td>Consumes vegetables, legumes or beans post weigh-in</td>
<td>34%</td>
<td>44%</td>
<td>22%</td>
</tr>
<tr>
<td>Consumes fruit post weigh-in</td>
<td>55%</td>
<td>37%</td>
<td>8%</td>
</tr>
<tr>
<td>Consumes grains/cereals/pasta/breads etc. post weigh-in</td>
<td>44%</td>
<td>50%</td>
<td>6%</td>
</tr>
<tr>
<td>Consumes meat or fish post weigh-in</td>
<td>37%</td>
<td>48%</td>
<td>15%</td>
</tr>
<tr>
<td>Consumes dairy post weigh-in</td>
<td>8%</td>
<td>55%</td>
<td>37%</td>
</tr>
<tr>
<td>Consumes fats/oils post weigh-in</td>
<td>8%</td>
<td>52%</td>
<td>40%</td>
</tr>
<tr>
<td>Consumes sports foods (bars, gels, drinks) post weigh-in</td>
<td>12%</td>
<td>62%</td>
<td>26%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>&lt;1 hr</th>
<th>1-2 hrs</th>
<th>&gt;2 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>How close to your fight do you consume solid foods</td>
<td>12%</td>
<td>58%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Chi square analysis determined reported frequencies to responses for each question were significantly different to chance (p < 0.01), except for “Consumes vegetables, legumes or beans post weigh-in” (p = 0.15).
Differences between reported frequencies to food group responses (Q5-11) were significant also ($\chi^2 (12, N=73) = 132.4, p < 0.001$).
Table 5.4 Athlete post weigh-in fluid intake choices

<table>
<thead>
<tr>
<th></th>
<th>Mostly</th>
<th>Often</th>
<th>Infrequently</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consume water post weigh-in</td>
<td>77%</td>
<td>22%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Consume soft drinks post weigh-in</td>
<td>0%</td>
<td>5%</td>
<td>18%</td>
<td>77%</td>
</tr>
<tr>
<td>Consume fruit juice post weigh-in</td>
<td>0%</td>
<td>18%</td>
<td>26%</td>
<td>56%</td>
</tr>
<tr>
<td>Consume milk post weigh-in</td>
<td>0%</td>
<td>15%</td>
<td>22%</td>
<td>63%</td>
</tr>
<tr>
<td>Consume meal replacement drinks post weigh-in</td>
<td>3%</td>
<td>16%</td>
<td>25%</td>
<td>56%</td>
</tr>
<tr>
<td>Consume protein supplements post weigh-in</td>
<td>3%</td>
<td>25%</td>
<td>25%</td>
<td>47%</td>
</tr>
<tr>
<td>Consume sports drinks post weigh-in</td>
<td>27%</td>
<td>47%</td>
<td>16%</td>
<td>10%</td>
</tr>
<tr>
<td>Consume electrolyte replacement drinks post weigh-in</td>
<td>29%</td>
<td>29%</td>
<td>16%</td>
<td>26%</td>
</tr>
</tbody>
</table>

Chi square analysis determined reported frequencies to responses for each question were significantly different to chance ($p < 0.01$), except for “Consume electrolyte replacement drinks post weigh-in” ($p = 0.46$).

Differences between reported frequencies to responses were significant also ($\chi^2 (21, N=73) = 489.9, p < 0.001$).

Factors influencing boxers’ food and fluid intake practices are displayed in Table 5.5. Thirst and hunger, as well as weight loss in the past 48 hours were key factors influencing dietary choices and volumes consumed post weigh-in.

Table 5.5 Influences on boxers post weigh-in food and fluid choices and volumes consumed

<table>
<thead>
<tr>
<th></th>
<th>Percentage of respondents indicating being influenced by this factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thirst/ hunger</td>
</tr>
<tr>
<td>Fluid</td>
<td>70%</td>
</tr>
<tr>
<td>Food</td>
<td>53%</td>
</tr>
</tbody>
</table>

Chi square analysis determined reported frequencies to responses for fluid and food were significantly different to chance ($p < 0.001$).

Differences between reported frequencies to responses between fluid and food were significant also ($\chi^2 (7, N=73) = 27.09, p = 0.0003$).
Discussion

This is the first study to measure BM re-gain during a multi-day boxing tournament and examine the relationship to competitive success. As expected, boxers BM increased significantly after official weigh-in. Males re-gained more BM than females and the lightest male weight division group displayed significantly greater BM re-gain than the heaviest weight division group. Longer recovery time after weigh-in, as found in bouts scheduled for the afternoon, were associated with greater BM re-gain. However, no differences in BM re-gain were found between finalists and non-finalists, between winners and losers of individual bouts, or between preliminary or final bouts. One interpretation of this finding is that under conditions in which there is a limited time for post weigh-in recovery, BM re-gain may no longer provide a surrogate measure of RWL in the days preceding the official weigh-in; indeed, the capacity for restoration of BM losses may be relatively clamped and therefore unable to address and differentiate small and large BM losses. Alternatively, since no differences existed between successful and less successful boxers with regard to BM re-gain, it could be argued that greater RWL and re-gain is not associated with competitive outcomes in boxing.

The boxers in our study re-gained significant amounts of BM after weigh-in, as has been shown in other Olympic combat sports of taekwondo(48), wrestling(46, 52) and judo (138), as well as in previous research examining boxers(7). The magnitude of BM re-gain was considerably less for the boxers in the current study than reported in this latter study in which boxers participated in a tournament where the official weigh-in was held the day-before competition (1.93±1.64% BM vs 4.4±3.3% BM)(7). Larger BM re-gain has been also been shown in other combat sports in which weigh-in is conducted on the previous day(52, 138); this suggests that fighters exploit the increased potential to acutely reduce and re-gain BM provided by larger recovery times.
Although our observation of greater BM re-gain in male athletes is not a universal finding of similar studies in other sports (48, 138), this finding may reflect the greater muscle and water mass of men than women at a given weight. Assuming body water manipulation is the dominant contributor to acute BM fluctuations, males would have greater capacity to acutely reduce and re-gain BM. Alternatively the greater magnitudes of BM re-gain displayed by the males in this study may be related to their greater experience and higher calibre, factors that are also known to correlate with more extreme RWL (13, 15, 21) practices. Indeed, there were a larger number of males than females in the present competition, suggesting greater ‘depth in competition’; this mirrors the general finding within the sport of boxing in Australia. The difference in BM re-gain between the lightest and heaviest male weight division groups in the present study indicates that the RWL of these athletes are more extreme than others. Results of this study support earlier findings of more extreme RWL of combat sport athletes in lighter weight divisions (46, 52). A possible reason for this difference is that athletes attempt to compete in weight divisions with fewer competitors (which was the case in the present study). Furthermore, the smaller absolute weight intervals between the lighter weight divisions relative to the heavier weight divisions may increase the temptation for athletes to undertake more extreme RWL. Alternatively, there may be an absolute threshold for RWL that boxers aim to achieve which leads to a greater BM re-gain in lighter boxers when expressed as a percentage.

The protocols of competition in this boxing tournament permitted observations of potential differences in behaviour over successive bouts across a competition as well as changes according to the scheduled timing of the bout in the day. We observed greater BM re-gain when bouts were scheduled later in the day (thus providing increased recovery time) which we attributed to recognition of the greater opportunities for, and benefits of, restoration of RWL. However, we failed to find differences in practices across successive bouts in the
competition (i.e. preliminary and final bouts). This suggests several factors combine to influence behaviour. First, it appears from both the survey responses and our observations of BM changes that boxers attempt to rehydrate and refuel as must as possible within their allotted (limited) recovery time, presumably considering this important for immediate performance, despite the implication that further RWL will be needed to achieve the subsequent weigh-in. Whether this finding would persist when competition rules allowed a longer recovery time (and more opportunity for greater fluid restoration and food intake) is unknown and may involve some individual calculation of the “cost” of re-losing the additional BM re-gain before the next weigh-in. A greater sample size in the current study would have allowed comparison between some boxers who fought (and weighed in) daily and those who fought less frequently in their progression to the final bout on the last day, due to a smaller number of competitors in their division.

Information collected in this study on recovery nutrition practices suggest that the boxers relied on their own experiences as well as internal perceptions (hunger, thirst, energy levels, taste preferences etc.) rather than expert advice, external influences or objective cues. This is in contrast to other reports in the literature on RWL practices of combat athletes in which the respondents identified coaches and other athletes as their primary influences (15, 21). Current sports nutrition guidelines for effective rehydration while minimising gut discomfort promote the slow consumption of fluids in volumes equivalent to ~ 150% of BM loss, supported by the replacement of sodium via electrolyte-containing beverages or sodium-rich foods (73, 140-142). By contrast, in the current study, water was the preferred rehydration beverage, with ~ half of the boxers failing to follow practices to consciously replace electrolyte losses. In addition, although boxers indicated that they reduced portion sizes of food while making weight, few purposely reduced fibre intake and many consumed fibre-rich/low energy foods in the post weigh-in recovery period. Therefore, they appeared unaware of the potential use
of a low-fibre diet to decrease the weight of gut contents (79), and thus promote weight loss without compromising fluid or nutrient intake for the first or subsequent bouts. Overall, this study suggests that further education is needed to assist boxers to improve their RWL and recovery practices. Whilst the present survey was constructed by relevant experts, it is acknowledged that it was not externally validated thus this must be considered when interpreting our findings and highlights the need for consolidation in this space in future research.

In contrast to the findings of studies in combat sports (46, 138), we failed to find a correlation between the BM re-gain and competitive success, either in terms of the outcomes of individual bouts or success in reaching the finals. As previously stated, this may be due to the circumstances of this boxing tournament in which BM re-gain is limited by opportunity and may not provide a true surrogate for the magnitude of RWL. However, another interpretation of the overall literature on this theme is that RWL and BM re-gain has no effect on competitive success in striking sports (48) (boxing and taekwondo) whereas an effect is seen in grappling sports (46) (judo and wrestling). These differences may be due to the technical nature of the sports; grappling involves the manipulation of an opponent’s BM whereas success in striking sports is more dependent on the tactical implementation of movements of one’s own BM thus small differences in BM and strength are less important. It has even been suggested that height is more important than BM in striking sports and that athletes should be separated by height rather than weight (12).

A final explanation for our findings is that in competitions where combat sport athletes are all of an elite or roughly equal standard, all competitors within a weight class engage in similar patterns of RWL and re-gain and any further benefit derived from qualifying for a lower weight class is negated by the universality of these practices. Indeed, the present study examined a national championship in which boxers had to be selected by their respective
state organisations to attend, thus achieving a more homogenous level of competition. Similarly, there was no benefit observed for greater BM re-gain in a study undertaken at a national wrestling competition in the USA in which athletes had qualified to attend (52). However, in competitions without qualification requirements, where there is a greater disparity in athlete experience and calibre, greater post weigh-in BM re-gain has been shown to correlate with improved chances of success (46, 138). Of course, this correlation does not show the direction of the cause and effect, since it is possible that the more successful athletes have endured in their sport because of their ability to tolerate more extreme weight making practices just as it is possible that greater RWL and BM re-gain are directly beneficial to competitive success.
Practical applications

While the degree of BM re-gain post official weigh-in did not influence success in this study, most boxers still engaged in RWL practices. Boxers understand the importance of recovering from RWL however their understanding of optimal BM loss and recovery strategies is not ideal. Sports nutrition professionals should deliver targeted education to combat sport athletes and coaches to improve RWL practices and subsequent recovery to optimise performance while ensuring the health and well-being of the athlete. Unlike other combat sports, the magnitude of BM re-gain during (limited) recovery periods and the necessity to weigh-in for successive bouts may not reflect the severity of weight making practices.
Conclusion

The majority of boxers practice RWL and BM re-gain pre and post official weigh-in, respectively. Despite the requirement to repeatedly make weight throughout a multi-day competition, boxers focus on restoring BM losses as much as possible before a bout, with extended recovery times resulting in greater BM re-gain. In this study, the requirement to make weight for a following bout had no influence on BM re-gain. RWL and BM re-gain appear to have no effect on competitive success (at least in the present investigation). While boxers recognise the importance of adequate hydration, fuelling and recovery; many do not appear to understand optimal methods to achieve this, thus further education is warranted.
Acknowledgments

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All the authors declare that they have no conflict of interest derived from the outcomes of this study.
Chapter 6
STUDY FOUR

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Journal of Sport Sciences:

“Body composition of elite Olympic combat sport athletes”

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Abstract
Physique traits of a range of elite athletes have been identified; however few detailed investigations of Olympic combat sports (Judo, Wrestling, Taekwondo and Boxing) exist. This is surprising given the importance of body composition in weight category sports. We sought to develop a descriptive database of Olympic combat sport athletes, compare variables relative to weight division and examine differences within and between sports. Olympic combat sport athletes (56♂, 38♀) had body mass (BM), stretch stature and dual-energy X-ray absorptiometry derived body composition assessed within 7-21 days of competition. Most athletes were heavier than their weight division. Sport had an effect (p<0.05) on several physique traits, including; lean mass, lean mass distribution, stretch stature and BMI. BM was strongly positively correlated (r>0.6) with; fat free mass, fat mass and body fat percentage, however was not predictive of total mass/weight division. The Olympic combat sports differ in competitive format and physiological requirements, which is partly reflected in athletes’ physique traits. We provide potential reference ranges for lean and fat mass across a range of BM. Lighter athletes likely must utilise acute weight loss in order to make weight, whereas heavier athletes can potentially reduce fat mass.
Introduction

Previous research has identified unique physique traits of elite performers in a variety of sports such as swimming (143), athletics (144, 145), skiing (146), football (147), rowing (148, 149) and aesthetically judged sports (150-152), among others. Physique traits optimising performance differ between events; for example low body mass (BM) and body mass index (BMI) is associated with success in distance running (153, 154), whereas in sports requiring strength and power, muscle mass is associated with performance outcomes (143, 147). In ‘complex’ sports involving increased tactical and strategic elements and wider ranges of potential movement patterns, the association between physique traits and success is weaker (145).

One group of sports which has received relatively little investigation in this context is Olympic combat sports, including boxing, taekwondo, judo and wrestling. This is surprising given these sports have specified weight divisions, established to ‘even the playing field’ by matching athletes of similar size. It’s common practice for athletes to reduce BM to compete in a lower weight category, via a combination of acute and chronic weight loss strategies, presumably to obtain a size or leverage advantage over smaller opponents. Data exists suggesting heavier athletes are more successful within a specified weight category (46, 138); however, this remains contentious and may vary across combat sports and competition level (46, 48, 52, 128). Often grouped together, Olympic combat sports can be separated into striking (boxing and taekwondo) and grappling (judo and wrestling). In striking sports, athletes utilise movement and distance, attempting to land blows with their hands (i.e. boxing), or with their feet/legs, the predominant scoring strikes in taekwondo. In grappling sports, competitors attempt to manipulate the opponent’s BM to throw them to the ground, pin or force the opponent to submit. These differences likely alter the physique characteristics associated with success. Understanding the differences in morphological optimisation
between combat sports is important for talent identification and transfer initiatives. Further, this information provides benchmarks for individual athletes, assisting in the identification of ideal weight divisions or the manipulation of body composition within a weight division.

Acute weight loss strategies employed by combat sport athletes to ‘make weight’ have been shown to have adverse health and/or performance implications (16, 23, 113). Recognising this, recommendations have been proposed discouraging acute weight loss, including the introduction of additional weight classes, creation of policies relating to weight regain allowances following weigh-in, scheduling weigh-ins closer to competition and targeted education (31, 32, 91, 155, 156). For example, the National Collegiate Athletic Association (NCAA) have implemented such strategies in wrestling, identifying an annual minimum weight category in which an athlete can compete, based on their presenting body composition (setting minimum weight at a value corresponding with 5 and 12% body fat in males and females, respectively; and requiring euhydration at weigh-in). Research suggests this initiative is changing BM management practices (129, 157); however the implications of applying similar strategies to other combat sports are unknown.

Accordingly, the aim of this study was to examine elite Olympic combat sport athletes’ body composition profiles and build a descriptive database. Additionally, we sought to examine the appropriateness of athletes’ self-selected weight classes compared against an internationally recognised classification system (the NCAA minimum wrestling weight scheme used to identify minimum ‘safe’ weight).
Materials and Methods

Overview
Olympic combat sport athletes participated in a cross-sectional observational study examining body composition (estimated via dual energy x-ray absorptiometry (DXA)) in relation to competitive weight division within and between Olympic combat sports. DXA scans were performed within 7-21 days of competition thus representing close to ‘competition body composition’ yet presumably before acute weight loss had begun. The Higher Research Ethics Committee of the Australian Institute of Sport (AIS), Canberra, Australia approved the study. Subjects provided written informed consent.

Participants
Male and female Judo, Boxing, Wrestling and Taekwondo athletes attending various training camps at the AIS volunteered for this study. Subjects were either members of the Australian national team or visiting overseas national teams.

Body composition measurements
Subjects underwent BM, stretch stature and DXA derived body composition measurements. Stretch stature was measured with a stadiometer (Harpenden, Holtain Limited, Crymych, United Kingdom) to the nearest 0.1cm using a standardised protocol (158). BM was measured on a calibrated scale to the nearest 0.01kg (Tanita, Japan, BWB800S). DXA scans were performed in accordance with a previously developed protocol emphasising; standardised participant presentation and positioning, and scanner quality assurance processes (159). Scans were performed in whole body mode on a fan beam scanner (Lunar Prodigy, GE Healthcare, Madison, WI) with analysis performed using the GE enCORE 2015 software (GE Healthcare) and the Geelong reference database. Standard thickness mode was utilised,
determined via the auto scan feature then analysed automatically by the Encore software, with regions of interest reconfirmed by the technician.

**Data analysis**

Descriptive statistics were reported for subjects; mean BM (kg), stature (m), bone mass (g and %), lean mass (kg and %), fat mass (kg and %), BMI (kg/m$^2$), fat mass index (FMI) (kg/m$^2$) and fat free mass index (FFMI) (kg/m$^2$) for each sport by sex. Athletes competing in divisions with no upper weight limit were excluded from analyses examining relationships relative to weight division.

For between-sport within sex comparisons, Levene’s test of homogeneity was conducted followed by one-way ANOVA with Tukey post-hoc tests. Between-sport and sex comparisons were made of total and lean mass relative to weight division (expressed as percentage of weight division upper limit), plus lean mass distribution (lower body and peripheral lean mass relative to total lean mass); this involved Levene’s test of homogeneity, followed by two-way ANOVA with Sidak post-hoc tests. Analysis was completed using PRISM v 6.0 (GraphPad Software, San Diego, California, USA). Subjects were grouped by sex and simple linear regressions calculated to predict: total mass/weight division, lean mass/weight division, body fat percentage, BMI, FFMI and FMI based on BM.

Significance was set as $p<0.05$. Additionally, 95% confidence intervals (CI95%) and effect sizes (ES) are reported when appropriate. The magnitudes of ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large ($\geq$0.80) when examining differences between means and as trivial (0–0.09), small (0.10–0.29), medium (0.30–0.49) and large ($\geq$0.50) when examining correlation coefficients using the scale advocated by Cohen (4). All data are expressed as mean ± SD, unless otherwise specified.
Results

Subject characteristics

Ninety-four athletes met inclusion criteria for the study. Two males (one boxing and one judo athlete) and two female taekwondo athletes competed in weight divisions with no upper weight limit, thus were excluded from analysis examining variables relative to weight division. BM, stretch stature and body composition compartments expressed in absolute and relative terms are displayed for males and females in Tables 6.1 and 6.2, respectively.

Significant differences were found between sports in males for BM (p=0.0283), total bone mass (p=0.0045), lean mass percentage (p=0.0036), total fat mass (p=0.0078), fat mass percentage (p=0.0061), BMI (p=<0.0001), FMI (p=0.0029) and FFMI (p=0.0012). Boxing and judo athletes differed similarly from taekwondo athletes across several measures (Table 6.1). Large effect sizes were found between male taekwondo athletes and all other athletes for differences in FFMI and BMI. Further differences were noted between taekwondo athletes and athletes from wrestling and judo in FMI.

Significant differences were found between female athletes for FFMI (p=0.0100), with taekwondo athletes lower than wrestling athletes (2.751 kg/m², ES=1.4; CI95% [0.55, 4.95]). Large effect sizes were found between female taekwondo and all other athletes for differences in FFMI; and between taekwondo, wrestling and judo athletes in FMI and BMI.

When analyses excluding athletes in divisions with no upper limit, mean values differed slightly however significant findings and trends remained – additionally stature differed between male boxing and taekwondo athletes (p = 0.0149) under these conditions.
Table 6.1 Male subject characteristics (mean ±SD). Data are collapsed across weight divisions

<table>
<thead>
<tr>
<th></th>
<th>Boxing (n=15)</th>
<th>Judo (n=17)</th>
<th>Taekwondo (n=10)</th>
<th>Wrestling (n=14)</th>
<th>Mean (n=56)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body mass (kg)</strong></td>
<td>67.6±16.2</td>
<td>80.7±14.9</td>
<td>68.1±8.5</td>
<td>76.2±11.0</td>
<td>73.2±12.7</td>
</tr>
<tr>
<td><strong>Stature (m)</strong></td>
<td>1.71±0.13</td>
<td>1.76±0.09</td>
<td>1.80±0.06</td>
<td>1.77±0.05</td>
<td>1.75±0.09</td>
</tr>
<tr>
<td><strong>Bone mass (g)</strong></td>
<td>3352±782</td>
<td>4114±731</td>
<td>3259±455</td>
<td>3721±576</td>
<td>3659±737</td>
</tr>
<tr>
<td><strong>Bone mass (%)#</strong></td>
<td>5.0±0.4</td>
<td>5.1±0.4</td>
<td>4.8±0.3</td>
<td>4.9±0.4</td>
<td>5.0±0.4</td>
</tr>
<tr>
<td><strong>Lean mass (kg)</strong></td>
<td>57.8±12.2</td>
<td>64.4±9.3</td>
<td>58.8±7.3</td>
<td>62.2±7.8</td>
<td>61.1±9.7</td>
</tr>
<tr>
<td><strong>Lean mass (%)#</strong></td>
<td>85.9±4.3</td>
<td>80.4±5.5</td>
<td>86.4±1.5</td>
<td>81.9±6.1</td>
<td>83.3±5.4</td>
</tr>
<tr>
<td><strong>Fat mass (kg)</strong></td>
<td>6.6±4.4</td>
<td>12.3±6.7</td>
<td>5.9±1.5</td>
<td>10.4±6.2</td>
<td>9.1±5.9</td>
</tr>
<tr>
<td><strong>Fat mass (%)#</strong></td>
<td>9.1±4.3</td>
<td>14.5±5.7</td>
<td>8.8±1.7</td>
<td>13.1±6.3</td>
<td>11.7±5.5</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>22.7±2.1</td>
<td>26.1±3.4</td>
<td>20.7±1.7</td>
<td>24.2±2.6</td>
<td>23.7±3.2</td>
</tr>
<tr>
<td><strong>FMI (kg/m²)</strong></td>
<td>2.1±1.1</td>
<td>3.9±2.0</td>
<td>1.8±0.4</td>
<td>3.3±1.9</td>
<td>2.9±1.8</td>
</tr>
<tr>
<td><strong>FFMI (kg/m²)</strong></td>
<td>19.5±1.6</td>
<td>20.8±1.9</td>
<td>17.9±1.4</td>
<td>19.8±1.7</td>
<td>19.7±1.9</td>
</tr>
</tbody>
</table>

a - difference to judo, b - different to TKD, *p≤0.05, **p≤0.01, ***p≤0.001, ****p≤0.0001

BMI = body mass index, FMI = fat mass index, FFMI = fat free mass index

# - percentage of total mass
| Table 6.2 Female subject characteristics (mean ±SD). Data are collapsed across weight categories |
|-----------------------------------------------|---------------|---------------|---------------|---------------|-------------------|
|                                              | Boxing (n=17) | Judo (n=7)    | Taekwondo (n=9) | Wrestling (n=5) | Mean (n=38)       |
| **Body mass (kg)**                           | 60.6±10.8     | 68.1±11.4     | 59.9±9.8       | 65.6±8.0       | 62.5±10.5         |
| **Stature (m)**                              | 1.64±0.05     | 1.66±0.05     | 1.68±0.07      | 1.63±0.03      | 1.65±0.06         |
| **Bone mass (g)**                            | 2826±447      | 3102±549      | 2736±386       | 2987±301       | 2877±441          |
| **Bone mass (%)#**                           | 4.7±0.3       | 4.6±0.4       | 4.6±0.5        | 4.6±0.4        | 4.6±0.4           |
| **Lean mass (kg)**                           | 43.9±4.9      | 47.4±4.0      | 43.0±4.8       | 47.8±7.2       | 44.8±5.2          |
| **Lean mass (%)#**                           | 73.3±6.1      | 70.6±7.5      | 72.3±5.2       | 73.8±14.0      | 72.6±7.3          |
| **Fat mass (kg)**                            | 13.9±6.3      | 17.6±7.9      | 14.2±5.7       | 14.8±10.4      | 14.8±6.9          |
| **Fat mass (%)#**                            | 22.0±6.2      | 24.9±7.6      | 23.1±5.5       | 21.6±14.2      | 22.7±7.5          |
| **BMI (kg/m^2)**                             | 22.5±3.2      | 24.5±3.2      | 21.3±3.1       | 24.7±3.4       | 22.9±3.3          |
| **FMI (kg/m^2)**                             | 5.1±2.1       | 6.3±2.7       | 5.0±1.9        | 5.6±4.1        | 5.4±2.4           |
| **FFMI (kg/m^2)**                            | 17.4±1.4      | 18.1±0.8      | 16.3±1.4^**    | 19.0±2.4       | 17.5±1.6          |

a - different to wrestling, **p≤0.01

BMI = body mass index, FMI = fat mass index, FFMI = fat free mass index

# - percentage of total mass

**Total and lean mass relative to weight division**

Differences between sports and sexes for total and lean mass relative to weight division are displayed in Figure 1. One female taekwondo athlete was lighter than the upper limit of her weight division (<73kg division). Eight males were lighter than the upper limit of their weight divisions; three wrestling athletes (one <74kg and two <86kg athletes), three judo athletes (one <60kg and two <100kg athletes) and two boxing athletes (one <54kg and one <91kg athlete).
No significant effect of sport or sex was observed for total mass relative to weight division, although large effect sizes were found between female boxers and female taekwondo athletes (ES = 0.84); and between female boxers and female judoka (ES = 1.08). A medium effect size was found between female boxers and female wrestlers (ES = 0.61). In males, medium effect sizes were found for the differences between boxers and taekwondo athletes (ES = 0.50); and between wrestlers and taekwondo athletes (ES = 0.62).

Regarding lean mass relative to weight division, significant effects were found for sex (F (1, 82) = 35.65, p=<0.0001) but not for sport, and no interaction was found between sex and sport. Large effect sizes were found between male taekwondo athletes and male wrestlers (ES = 1.13); between male taekwondo athletes and male judoka (ES = 1.24); and male boxers and male judoka (ES =0.82).

**Comparison of selected weight division to NCAA minimum ‘safe’ weight recommendations**

Across sports, two female athletes competed in divisions below the NCAA minimum safe weight. Both were wrestlers competing in the <48kg and <58kg divisions with identified minimum safe weights of 54kg and 68kg, respectively. In the male cohort; one boxer, taekwondo and wrestling competed in the <49kg, <58kg and <74kg divisions with identified minimum safe weights of 50kg, 61kg, 75kg, respectively.
Figure 6.1 Total body mass and lean mass relative to weight division.
Values expressed as percentage of weight division (Box limits indicate range with mean marked with horizontal line). Analysis of subjects by sex and sport for; total body mass relative to weight division (A) and lean mass relative to weight division (B). Two way-ANOVA revealed an effect for sex on lean mass relative to weight division. ^ denoted within sex large effect size.
Relationships between body mass and body composition

Simple linear regression graphs with 95% confidence bands are displayed in Figure 2 and Figure 3. No significant relationship was found between BM and total mass/weight division. However lean mass/weight division, body fat percentage, BMI, FFMI and were strongly correlated with BM in males and females.
Figure 6.2 Linear regression of body mass and; total mass and lean mass relative to weight division, and body fat.
Individual male and female athletes’ body mass compared to: total mass/weight division (A and B), lean mass/weight division (C and D) and body fat percentage (E and F). Solid lines indicate linear regression. Dotted lines indicate 95% confidence bands.
Figure 6.3 Linear regression of body mass and: body mass index, fat free mass index and fat mass index

Individual male and female athletes’ body mass compared to: body mass index (A and B), fat free mass index (C and D) and fat mass index (E and F). Solid lines indicate linear regression. Dotted lines indicate 95% confidence bands.
Lean mass distribution

Differences between sports and sexes in lean mass distribution are displayed in Figure 4. Sex had a significant effect on peripheral/trunk lean mass distribution (F (1, 86) = 12.31, p=0.0007), however neither an effect for sport nor interaction between these variables was evident.

Sport had a significant effect on lower/upper lean mass distribution (F (3, 86) = 9.996, p<0.0001); however, no effect of sex and no significant interaction was revealed. Post-hoc analysis revealed significant differences for lean mass distribution (lower body/total lean mass) between male taekwondo and boxing athletes of 2.32 (ES=1.31; CI95% [0.24, 4.39]); male taekwondo and wrestling athletes 2.29 (ES=1.27; CI95% [0.19, 4.40]); and female taekwondo and boxing athletes 2.35 (ES=1.40; CI95% [0.25, 4.45]).

Large effect sizes were found between female taekwondo and wrestling athletes (ES = 1.10) and also between female boxing and judo athletes (ES = 0.95). Medium effect sizes were found between male boxing and judo athletes (ES = 0.75); male judo and wrestling athletes (ES = 0.70); male judo and taekwondo athletes; female wrestling and judo athletes (ES = 0.65); and female taekwondo and judo athletes (ES = 0.55).
Figure 6.4 Lean mass distribution.
Values expressed as percentage of total lean mass (mean ±SD). Analysis of subjects by sex and sport for; lower body lean mass relative to total lean mass (A), peripheral (arms + legs) lean mass relative to total lean mass (B). Two-way ANOVA revealed an effect of sex on peripheral/axial lean mass distribution and effect of sport on lower/upper body lean mass distribution. ^ denoted within sex large effect size.
**Discussion**

This is the first investigation to present DXA-derived body composition data across elite Olympic combat sport athletes, reporting on absolute physique traits as well as traits relative to weight division. The primary findings were; 1) the vast majority of athletes were heavier than their competitive weight division 7-21 days before competition, yet few were outside of accepted weight division guidance classification; 2) total BM was predictive of multiple physique traits; and 3) certain physique traits were unique to individual sports.

Detailed body composition data on combat sport athletes is scarce. Most research has investigated physique traits superficially, utilising indirect indices of composition, such as subcutaneous skinfold measurements and associated estimates of whole body composition derived from regression equations (6, 8, 132, 135) or bioelectrical impedance which may not be valid to assess body composition in individuals and/or combat sport athletes (160). DXA is recognised as the preferred choice for physique assessment of athletes, notably for athletes in weight sensitive sports (161). DXA quantifies whole body and regional bone, fat and fat free mass and when validated against a reference four compartment model, has been shown to accurately measure fat mass within 1% across a range of diverse athletes (162). Despite this, few DXA investigations have examined combat sport athletes, and those doing so have failed to report their findings in a context relevant to combat sports (14, 163-165), including relationships to weight division or regional mass distribution.

In this study, mean BM of the athletes was 4.3±3.9% greater than their competitive division; similar to the magnitude of acute weight loss commonly reported; ~5% (15, 21, 166). Female boxers in our sample tended to be closer to their weight division than other athletes. This finding is of no surprise given the rules of amateur boxing which schedule weigh-ins on the morning of competition, providing minimal time for athletes to recover from acute weight loss practices unlike other combat sports. This pattern was not as pronounced in males;
taekwondo athletes displayed greater BM relative to their weight division in comparison to boxing and wrestling athletes (evidenced by medium effect sizes) yet no differences were observed between boxers, judokas and wrestlers. Our findings support earlier survey data (13, 15, 21) and studies using other indirect indices of acute BM management (46, 48, 52, 138) which collectively suggest that most combat sport athletes utilise acute weight loss prior to weigh-in. Acute weight loss of ~5% is known to impact performance measures in combat sport athletes with limited recovery time (167), however with ≥4 hours following weigh-in, alongside appropriate nutrition interventions, performance can be restored (71, 168). In our study, we observed low body fat levels amongst athletes, which suggests that significant fat loss was unlikely during the pre-competition period to make weight. Indeed, losses in fat mass towards weigh-in goals in combat athletes may be as little as 0.5kg per week with the rate slowing as athletes become leaner (120). As athletes were significantly above their weight division, it’s likely they would be engaging in acute weight loss to achieve their weight division. Although few athletes in our study were competing at weights below ‘minimum safe weight’, if resorting to acute weight loss strategies these athletes would likely violate NCAA guidelines prohibiting dehydration at weigh-in; demonstrating the multi-pronged approach required for interventions aimed at reducing acute weight loss practices.

While acute weight manipulation before competition is a (commonly perceived) key part of a combat sport athlete’s preparation (44), research on ‘weight making strategies’ and the effect on success is mixed. Some studies utilise BM re-gain post weigh-in as a surrogate for the magnitude of acute weight loss pre-weigh-in (13-17). Such studies have reported correlations between BM re-gain and success in judo (138) and wrestling (46), however this may depend on competition level (52). By contrast, this relationship has not been observed in boxing (128) or taekwondo (48). Similar inconsistencies have been reported with other parameters:
higher stature and lower BMI have been correlated with success in taekwondo (9-11, 169, 170) but not in boxing, judo or wrestling (8, 171, 172) (admittedly thorough investigation into correlates between many physique traits and success are yet to be conducted or have only been done in unrepresentative samples/ small sample sizes). In our study, significant differences and large effects sizes existed between taekwondo and the other sports for BMI, FFMI and FMI, underscoring the relationship between lighter built, taller athletes and success in taekwondo. The nature of the scoring system in taekwondo may explain the advantage afforded by height/reach as minimal contact is required to score relative to other combat sports and greater scores awarded for kicks compared to punches, favouring longer levers.

Our results also revealed differences in lean mass distribution between sports. Taekwondo athletes possessed proportionally the most lower body lean mass, followed by judoka, then wrestlers, and lastly boxers. It is of interest to note sport had a larger effect on upper/lower body lean mass distribution than sex, since males typically possess higher relative upper body lean mass than females (173). This finding likely reflects the individual demands of the sports and the unique effects of training stresses placed on athletes. As previously outlined, competition goals and scoring requirements differ between sports, thus specific physique traits predispose athletes to competitive success.

In contrast to the clear differences observed between combat athletes across sports, similarities included the relationship between BM and several body composition/physique traits. We found strong correlations between BM and; BMI, FFMI, FMI as well as relative lean and fat mass. In general, these findings suggest that athletes become more heavily built as BM increases. The correlation between percentage body fat and BM suggests lighter athletes are less able to make weight through body fat reduction alone, thus rely heavily on acute weight loss strategies (such as dehydration), whereas heavier athletes have greater capacity to decrease body fat to make weight.
The results of this study extend previous findings focusing globally on combat sport athletes’ body composition, which commonly collapse athletes across weight divisions. Previous comparisons between weight divisions have revealed trends of increasing body fat and endomorphy with BM (5, 8), however DXA measurements are scarce. Santos et al. did utilise DXA in estimating mean body fat percentages in grapplers (12.2% in males and 23.0% in females) and strikers (12.9% in males and 27.6% in females) (14), however failed to analyse these findings relative to weight division/BM. These earlier data are inline with our mean findings (11.7% in males and 22.7% in females). Linear regression analysis of our data allowed predictions of potential benchmarks (i.e. body fat percentage targets) across varying weights, and found that regardless of BM, athletes all weighed a similar relative amount above their weight division. This suggests that athletes plan for relative rather than absolute acute weight loss. This contrasts some earlier reports that athletes in lighter weight divisions utilise larger acute weight manipulations (46, 52, 138). While the body fat percentage values reported in this study may representative of what is realistically achievable, care should be taken when using these bench marks as precise recommendations or using values of physique traits aside from body fat percentage to guide recommendations, as these other parameters have less support from existing research.

Limitations in this study include; small sample sizes, the cross sectional design, and lack of additional anthropometric measures (i.e. leaver length). Thus, it is difficult to draw robust conclusions on ‘optimised’ body composition for combat sport athletes. Furthermore, although athletes were assessed close to competition, in the range of 7-21 days, it is possible (although perhaps unlikely) that some athletes may have continued to achieve chronic BM reductions and therefore some data points may not truly represent ‘competition shape’ athletes. Lastly, we acknowledge that access to larger numbers of elite level wrestlers was not possible, and the lack of depth in high level competition in the region of the subjects
meant the same selection pressures on athletes evident among the other sports was not present. Therefore the representative nature of the pool of wrestlers was likely dilute (despite several elite wrestlers including Olympians being included in the study). Moving forward we recommend further investigation of physique traits at elite competitions and the relationships to success in order to determine to what degree morphological optimisation exists. However, this body of work adds value to existing literature; highlighting differences between combat sport athletes, examining how BM/weight division influences body composition targets and strengthening the case that low BMI, FMI and FFMI are favourable for performance in taekwondo.
Conclusion
Olympic combat sports differ in rules and regulations as well as physiological requirements, which is partly reflected in athletes’ physique traits. While total BM relative to weight division during the pre-competition period is similar across weight divisions (at least in this sample), differences exist in body composition across athletes of varying BM, with heavier athletes possessing greater lean and fat mass relative to height. We provide reference ranges for lean and fat mass across a range of weight divisions which provides a guide for combat sport athletes’ in their chronic BM management efforts and in identifying a suitable weight division. As lighter athletes are leaner, these athletes likely rely heavily on acute weight making strategies during the pre-competition period to make weight compared to athletes in heavier weight divisions. These athletes were shown to have greater body fat levels and as such have greater potential to lose body fat during the pre-competition period to make weight. Lean mass distribution differs between sports with taekwondo athletes possessing the greatest relative lower body lean mass, followed by judoka, wrestlers and boxers who possess the greatest relative upper body lean mass. In taekwondo, lower BMI, body fat, and lean mass for height, and a propensity for lower body lean mass relative to upper body lean mass appears beneficial.
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Chapter 7
STUDY FIVE

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“Water loading as a means to acutely manipulate body mass”

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Abstract

BACKGROUND/AIM: Novel methods of acute weight loss practiced by combat sport athletes include ‘water loading’; the consumption of large volumes of fluid for several days prior to restriction. We examined claims that this technique increases total body water losses, while also assessing the risk of hyponatremia. METHODS: Male athletes were separated into control (CON, n=10) and water loading (WL, n=11) groups and fed a standardised energy-matched diet for 6 days. Day 1-3 fluid intake was 40 mL·kg⁻¹ and 100 mL·kg⁻¹ for CON and WL, respectively with both groups consuming 15 mL·kg⁻¹ on Day 4 and following the same rehydration protocol on Days 5-6. We tracked body mass (BM), urine sodium, specific gravity (USG) and volume, training-related sweat losses and blood concentrations of renal hormones and urea and electrolytes (U+Es) throughout. Physical performance was assessed pre and post-intervention. RESULTS: Following fluid restriction, there were substantial differences between groups in the ratio of fluid input/output (39%, p < 0.01, ES=1.2) and BM loss (0.6%BM, p=0.02, ES=0.82). Changes in USG, U+Es and renal hormones occurred over time (p < 0.05), with an interaction of time and intervention on blood sodium, potassium, chloride, urea, creatinine, USG and vasopressin (p < 0.05). Measurements of U+E remained within reference ranges and no differences in physical performance were detected over time or between groups. CONCLUSION: Water loading appears to be a safe and effective method of acute BM loss under the conditions of this study. Changes in vasopressin may partially explain the mechanism of increased body water loss with water loading.
Introduction

Combat sport athletes commonly manipulate body mass (BM) prior to competition, attempting to gain real or perceived advantages by competing in weight divisions lighter than their day-to-day training weight (13). In addition to longer term BM reductions via fat loss, athletes acutely reduce BM prior to weigh-in. Common and effective methods include increased exercise, saunas, sweat suits, diuretics, fluid restriction and sodium manipulation to reduce total body water and reduction of gut contents via laxative use, fasting, skipping meals, reducing food volume and modification of carbohydrate or fibre intake (16, 113).

‘Water loading’ is a recent addition to these methods, and is claimed to decrease BM via increased urine production (113). This technique involves the consumption of large fluid volumes (i.e. 7-10+ L/d) for several days followed by fluid restriction; allegedly manipulating renal hormones to increase urine output/ net fluid losses relative to fluid restriction following ad-libitum fluid intake (113). There are anecdotes of the practice of this technique among body builders and power lifters as well as in combat sport. Recent research has confirmed the use of water loading by significant numbers of combat sport athletes internationally (91). However, these athletes commonly manipulate sodium and other nutrients concurrent to fluid intake while ‘making weight’, thus confounding the ability of anecdotal ‘evidence’ to provide insights into its efficacy. Given the prevalence of use, the lack of scientific investigation and the potential risk of hyponatremia associated with consuming large volumes of fluid, research into this practice is warranted. Accordingly the aim of this study was to examine the process of water loading in a controlled setting, investigating the efficacy, safety and underlying mechanisms (if any).
Methods

Overview

This study was conducted at the Australian Institute of Sport as a parallel intervention, with subjects being separated into a control (CON) or intervention group (water loading (WL)), matched for BM. The study was approved by the Human Ethics Committee of the Australian Institute of Sport, with subjects providing written informed consent prior to participation. The project took place over eight days: two ‘pre’ testing days prior to the intervention (Day -1 and 0), six intervention days (Day 1-6) and post’ testing (Day 6). Figure 1 provides an overview of the study. Figure 2 summarises timelines and details of key data collection points.
**Figure 7.1 Study outline.**

DXA- dual energy x-ray absorptiometry, WL – water loading group, CON – control group
Figure 7.2 Laboratory data collection and Physical testing timeline.
Laboratory data collection conducted morning and evening each intervention day and physical testing undertaken on days -1 and 0 (pre-intervention) and day 6 (post-intervention). USG – urine specific gravity, Na – sodium, K – potassium, Cl – chloride, U – urea, Cr – creatinine, IMTP – isometric mid thig pull, IBP – isometric bench press, CMJ – counter movement jump, RSA – repeated sprint ability.
Subjects

Subjects were 21 male competitive combat sport athletes. Matched groups were randomly assigned to CON (n = 10; 77.2±8.7kg, 178.9±5.7cm, 24.9±4.0years) or WL (n = 11; 77.8±8.0kg, 176.2±6.4cm, 28.3±3.5years).

Body composition assessment

On Day -1, body composition was assessed by a trained technician, using dual energy x-ray absorptiometry (iDEXA GE Healthcare, Madison, WI) according to the standardised protocol developed at the Australian Institute of Sport (174).

Physical performance testing

Physical performance measures included muscular strength/power and repeated sprint ability (RSA) tests (Fig 2). Subjects performed familiarisation sessions on Day -1, with pre-intervention testing being undertaken on Day 0 and replicated on Day 6. Testing was undertaken at the same time each day, following morning blood collection and a standardised breakfast. It was conducted by the same four scientists in a noise sensitive laboratory. Subjects were instructed to give maximal effort prior to testing, but not provided with encouragement during testing.
Testing consisted of a standardised ‘general’ warm-up followed by 3 maximal efforts of; a countermovement jump (CMJ), isometric mid-thigh pull and isometric bench press conducted on a force plate. Testing was completed according to the methodology and customised power rack used by Halperin et al (175). Subjects then performed the RSA test (12 all out sprints at a work rest ratio of 6:24 seconds), after a specific warm-up on a cycle ergometer (Wattbike Ltd, Nottingham, UK). Handlebar and saddle position/height were self-selected and replicated between trials.
Diets

Standardised diets during the intervention were provided an energy content of 125 kJ·kg FFM\(^{-1}\) to meet resting energy requirements, plus additional energy to account for exercise induced thermogenesis (estimated based on BM and training duration (176)). This represents a mild energy restriction while maintaining moderate energy availability (177): protein: 2.2-2.5 g·kg FF M\(^{-1}\), carbohydrate: 5-6 g·kg FF M\(^{-1}\) and fat: 1-2 g·kg FF M\(^{-1}\). Sodium prescription was ~300 mg·Mj\(^{-1}\) while fibre was 10-13 g, representing a reduced residue diet recommended to athletes “making weight” as a means to reduce the weight of gut content and overall BM.

Fluid prescription

During Days 1-3 of the intervention, fluid intake (tap water) was clamped at 100 mL·kg\(^{-1}\) BM for WL and 40 mL·kg\(^{-1}\) BM for CON. On Day 4, both groups restricted intake to 15 ml·kg\(^{-1}\) BM, while no fluid was consumed on Day 5 until after the morning laboratory data collection. Both groups followed the same re-hydration protocol after this point; fluid intake of 30 mL·kg\(^{-1}\) BM + 150% of the BM loss incurred during the fluid restriction period (morning of Day 4 until post Day 5 data collection). To ensure fluid prescriptions were achieved, daily targets were divided into an hourly volume to be consumed during waking hours.

Training

The training schedule aimed to replicate typical competition preparation of combat sport athletes, consisting of two training sessions daily during Days 1-3, one session on Day 4 and no training on the final intervention day.

Laboratory data collection
The standardised protocol for laboratory data collection (Fig 2) involved morning testing at 7 am (Day -1 to Day 6) and evening testing at 6 pm (Day 1-5). Each time point involved the collection of urine and venous and capillary blood, measurement of BM, blood pressure and heart rate, and completion of a gastrointestinal (GI) symptoms questionnaire.

**Body mass**

BM measurements were conducted after bladder voiding using the BWB800S digital BM scales (Tanita, Tokyo, Japan). In addition to laboratory data collection time points, naked BM was measured before and after training sessions and used alongside urine output and fluid intake to estimate training sweat losses (i.e. sweat loss = change in BM + fluid intake – urine output).

**Urine collection and analysis**

Waking urine samples were analysed for specific gravity (USG) using the UG-1 digital refractometer (ATAGO, Tokyo, Japan). Twenty-four hour urine collection was undertaken from Day 1-6 in 2 x daily collection periods, with measurement of volume and sodium concentration using the B-722 Laqua twin device (Horiba, Kyoto, Japan).

**Blood collection and hormone analysis**

Venous blood (26.5 ml per collection point) was collected by phlebotomists following ~30 min supine rest for renal hormones measurement (vasopressin, renin and aldosterone). Vasopressin concentrations were determination using the Buhlmann Vasopressin double-antibody radioimmunoassay method (Buhlmann Laboratories, Schönenbuch, Switzerland) based on the method of Glick and Kagan (178). Aldosterone and renin concentrations were determined by a LIAISON Analyser (DiaSorin Inc., Via Crescentino, Italy), using a
competitive assay (sheep monoclonal antibody) and a sandwich chemiluminescence immunoassay (specific mouse monoclonal antibody) respectively (179, 180).

Fingertip capillary blood (95uL) was then collected to analyse blood concentrations of sodium, potassium, chloride, urea and creatinine using the i-STAT Point of Care device and chem8+ cartridges (Abbott Laboratories, Abbott Pak, IL, USA).

**Heart rate and blood pressure**

Following blood collection, resting blood pressure and heart rate measurements were taken using the HEM-7325 automatic blood pressure monitor (Omron Healthcare, Kyoto, Japan).

**Gastrointestinal symptoms**

Three questions relating to GI symptoms associated with fluid intake from a validated questionnaire (181) were administered. Subjects rated feelings of nausea, bloating, and loss of appetite using a 1-7 Likert scale.

**Data analysis**

Conventional statistical analysis was used to calculate mean ± SD for each variable. Where appropriate, results were analysed and reported as absolute and/or delta scores. Repeated measures two-way-ANOVAs with Bonferroni post-hoc tests were used to compare between groups and across time using the PRISM v 6.0 statistical analysis package (GraphPad Software, San Diego, California, USA). Significance was set at p<0.05. Additionally, 95% confidence intervals (CI95%) and Cohen d effect sizes (ES) are reported when appropriate. The magnitudes of ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (≥0.80) according to Cohen (133).
Results

Body mass

Changes in BM are displayed in Figure 3. Time had a significant effect on cumulative and day-to-day changes in BM and an interaction between time and fluid intake was revealed. Within both groups, there was a significant cumulative change in BM change across each successive day, with the exception of Day 3 to Day 4 (P < 0.05). Rehydration returned BM at Day 6 to levels equivalent to Days 3 and 4.
Figure 7.3 Changes in body mass across the 6 day intervention.
Cumulative body mass (BM) change between groups, expressed as percentage of BM ±SD normalised to day 1 (A). Day to day BM change, expressed as percentage of BM ±SD (B). Two-way ANOVA revealed significant main effect of time on cumulative BM change and day to day BM change (p<0.0001), and an interaction between fluid intake and time on cumulative BM change (p=0.027) and day to day BM change (p=0.02). Within groups; significant differences were found for cumulative BM change between each day except; day 3/4, day 3/6 and day 4/6.
**Fluid balance and urine analysis**

Fluid balance and urine analyses are displayed in Figure 4. Main effects were found of time for all measures, for fluid intake on USG and an interaction was found between fluid intake and time for USG and fluid output.
Figure 7.4 Urine and fluid balance analysis across the 6 day intervention. Daily fluid output (urine + sweat), expressed as percentage of fluid intake ±SD (A). Daily urine sodium excretion, expressed as percentage of sodium intake ±SD (B). Daily waking urine specific gravity ±SD (C). Two-way ANOVAs revealed a main effect of time on; fluid output (p<0.0001), sodium excretion (p = 0.035) and urine specific gravity (p<0.0001), a main effect of fluid intake on urine specific gravity (0.029), and an interaction between time and fluid intake on; fluid output (p<0.0001) and urine specific gravity (p = 0.006).

Renal hormone changes are displayed in Figure 5. Main effects were found for time on all measures, and an interaction was found between fluid intake and time for changes in vasopressin.
Figure 7.5 Renal hormones measurements across the 6 day intervention. Hormone measurements expressed as fold change from baseline ±SD for; aldosterone (A), renin (B), aldosterone/renin ratio (C) and vasopressin (D). Two-way ANOVAs revealed a significant effect of time on aldosterone (p<0.0001), renin (p=0.0187), renin/aldosterone ratio (p<0.0001) and vasopressin (p<0.0001). A significant interaction was found between fluid intake and time on vasopressin.

Blood chemistry

Blood chemistry changes are displayed in Figure 6. Main effects were found of time for all measures, and an interaction was found between fluid intake and time for sodium, chloride...
and urea. No values approached critical values or deviated significantly from typical clinical reference ranges for greater than one time point.
Figure 7.6 Blood chemistry across the 6 day intervention.
Measurements expressed as mean values ±SD for; Sodium (A), Potassium (B), Chloride (C), urea (D), and creatinine (E). Two-way ANOVA revealed a main effect of time on sodium (p <0.0001), potassium (p<0.0001), chloride (p<0.0001), urea (p<0.0001) and creatinine (p<0.0001). A main effect of fluid intake on urea (p=0.0137) was found. An interaction between fluid intake and time on sodium (p=0.0096), chloride (p=0.0137) and urea (p=0.0043) was found.
Gastro intestinal symptoms
No effects of fluid intake or time on ‘loss of appetite’ were evident. A main effect of time for ‘Nausea’ (p=0.023) and ‘bloating’ (p=0.0005) was revealed, with nausea peaking (mean 1.2±0.1 during fluid restriction and bloating peaking (mean 1.4±0.2) prior to the standardised diets before reducing during the intervention.

Heart rate and blood pressure
A main effect of time for ‘heart rate’ (p<0.0001) was revealed, with heart rate being at its lowest on day 0am, day 5pm, and day 6 am. No differences existed between groups.

Physical testing
No differences existed between groups for any physical performance tests. A main effect of time (p=0.0354) for total work completed during the RSA test and for peak displacement in the CMJ test (p<0.0001) was found. Subjects completed more total work during the RSA post-test compared to the pre-test (pooled means; pre-test 7542.8±371.5W vs post-test 7790.5±301.1W). Peak displacement was higher in the CMJ post-test than the pre-test (pooled means; pre-test 45.4±1.3cm vs post-test 47.6±0.8cm).
Discussion

This is the first investigation of the effectiveness and safety of ‘water loading’ as a means of manipulating BM in the context of weight category sports. The key findings were water loading was effective in increasing fluid and BM loss accompanying fluid restriction; this may be mediated in part via the interventions effects on vasopressin. Water loading, at least as practiced in the current investigation, appears to be a safe technique to assist in the acute loss of BM prior to weigh-in since there was no evidence of problematic blood chemistry changes or impairment of physical performance following rehydration.

These results support anecdotal outcomes described by combat sport athletes. We found the intake of large volumes (100 mL.kg.d⁻¹ or ~ 7-8L/d) of water for 3 days prior to one day of fluid restriction (15 mL.kg.d⁻¹) was associated with increased urine production, both during the days of high fluid consumption and fluid restriction. Specifically, diuresis continued during fluid restriction, leading to greater fluid losses relative to intake on the day as well as the losses recorded for a control group who had consumed 40 mL.kg.d⁻¹ (~ 3L/d) prior to this day. This was effective in achieving greater BM loss following the 5 d intervention in the WL group than the CON group. The combination of 5 days of a potentially mild energy deficit and reduced residue diet, including 1 day of fluid restriction, achieved total BM losses of 3.2 and 2.4% for WL and CON groups, respectively.

This acute loss of BM was achieved in a scenario simulating the preparation for weigh-in and competition in combat sports, but without resorting to more extreme practices of severe energy restriction and active dehydration commonly observed (16). However before advocating water loading, investigation of safety concerns is necessary. It is well documented that excessive fluid intake is causative in hyponatremia (86) with substantial lowering of blood sodium leading to negative outcomes, including death (86, 182). In the present investigation, however, no clinical meaningful changes in blood chemistry occurred with
water loading, with perturbations following expected changes due to daily differences in fluid intake.

The present water loading strategy used did not appear to create a risk of hyponatremia; indeed in cases where fluid intake in healthy individuals has resulted in death have generally involved substantially greater intakes over much shorter time frames (e.g. >10 litres in 6 hours) (86, 182). Dilutional hyponatremia results when fluid ingestion rate exceeds the excretion capacity of the kidneys (86). Thus, in the present study, it appears dispersing intake across the day, allowed renal adjustments to compensate. The hormone analysis provides insight into the mechanism associated with maintenance of blood chemistry and effect of water loading on fluid output. No effect on renin or aldosterone was evident; however vasopressin decreased during the water loading phase in WL, before ‘rebounding’ to concentrations higher than baseline and higher than seen in the CON group following fluid restriction. Blood sodium decreased in the WL group during the water loading phase, but normalised in line with the CON group after water loading.

As vasopressin is under osmoregulation (183), the lowering of blood sodium in WL may explain the vasopressin suppression observed. Furthermore, vasopressin is known to bind to vasopressin-2 receptors (V2R) found within the collecting ducts of the kidneys. This initiates a metabolic cascade to increase the permeability of the collecting ducts, and thus water reabsorption back into the circulation, via the insertion of aquaporin water channels (184), notably; aquaporin-2 (AQP2) channels. Conversely, in the absence of vasopressin, AQP2 channels (thus water reabsorption) are reduced (184), assisting acute fluid regulation. This mechanism has been directly observed in rodent models, with 24 hours of water loading associated with a reduction in intramembrane AQP2 channels and water permeability in the kidney collecting ducts (185, 186). Additionally, infusion of vasopressin has been shown to increase AQP2 channels mRNA expression (185). In rats unable to manufacture endogenous
vasopressin infusion may take 3-5 days to ‘return’ mRNA expression of AQP2 channels to ‘normal’ levels (187). This possibly explains persistent fluid losses evident following fluid restriction in WL.

**Body mass losses prior to fluid restriction**

Significant BM losses (~1-2%BM) occurred in both groups following days 1 and 2, before plateauing until fluid restriction. It is possible the mild energy deficit allowed a loss of fat mass and/or glycogen. However the energy deficit required for this degree of fat loss is substantial and a major restriction of carbohydrate would be needed to create such glycogen depletion. Therefore, reduced gut content resulting from decreased fibre intake is the most plausible cause of the initial BM loss, especially considering the time frame. Low fibre/residue diets have been used by combat sport athletes and recommended by sports nutrition professionals (113) as a way to incur BM loss without the disadvantages associated with severe dehydration and energy restriction. Different foods possess different faecal bulking properties (79), with those high in fibre drawing water into the intestinal space, increasing stool bulk. Reducing dietary fibre reduces undigested plant matter, equating to reduced gut contents and lower BM. There is a linear relationship between fibre intake and bowel content (110), with the adoption of a low fibre diet for even two days helping empty the bowel (110) and seven days being as effective as pre-surgery bowel preparation formulas (111). Indeed, surgery preparation formulae have been shown to achieve BM reductions of 1.6% (108), in line with the ~1.5% BM loss in our study following 48 hours of lowered fibre intake. There is considerable variability in whole gut transit times (~10-96 hours) (112), but in the absence of investigations of low fibre diets in the context of weight making for weight category sports, the present findings could be valuable in identifying the timeframe required to achieve significant BM loss using this technique. The lack of a control group on a
“normal” (higher fibre) intake is a limitation of our study, however, the measurement of fluid balance in our groups eliminates hypohydration as a confounding variable. The use of low residue diets in weight-making warrants further investigation.

**Limitations**

The major limitation of this study is the lack of a standardised ‘lead-in’ period prior to the commencement of the controlled diets. Achieving stable BM and increasing confidence in the prescription of appropriate energy and carbohydrate intakes would have allowed greater certainty in interpreting the source of BM losses in days 1-2 of our intervention. However the standardisation which did take place prior to fluid restriction, combined with the careful observations of daily fluid input/output allows strong conclusions about the effect of water loading on fluid balance to be drawn.
**Conclusions**

Three days of dispersed consumption of large volumes of water (100 mL kg$^{-1}$ d$^{-1}$), prior to one day of fluid restriction, appears to be a safe and effective method of acutely reducing BM via a reduction in body water secondary to increased fluid losses. We suggest increased fluid consumption creates a small but physiologically significant reduction in blood sodium concentration, which suppresses vasopressin release and downregulates the appearance of AQP2 channels in the collecting ducts in the kidneys. When this is employed immediately prior to fluid restriction, there is a continuation of increased fluid loss leading to greater losses relative to fluid restriction alone.
What are the new findings?

- ‘Water loading’, an increasingly popular strategy of making weight prior to competition in weight category sports, is effective in assisting with the acute loss of BM, by continuing to promote diuresis when several days of consumption of large volumes of water are followed by a day of fluid restriction.

- Water loading, via the daily consumption of 100 mL·kg\(^{-1}\)BM fluid distributed throughout the day, does not appear to create a risk of developing problematic hyponatremia.

- Alterations in vasopressin release may in part explain the temporary diuresis that underpins the effectiveness of this intervention.
Acknowledgements

The authors would like to acknowledge all the participants involved in the study. Special thanks to all of the sports scientists, laboratory staff, phlebotimists and dietitians at the Australian Institute of Sport and took part in the study design and data collection.
Chapter 8
REVIEW OF POST WEIGH-IN NUTRITION RECOVERY, CONSOLIDATION OF RESEARCH AND PRACTICAL ADVICE FOR ATHLETES AND COACHES

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“Individualised dietary strategies for Olympic combat sports: Acute weight loss, recovery and competition nutrition”

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Abstract

Olympic combat sports separate athletes into weight divisions, in an attempt to reduce size, strength, range and/or leverage disparities between competitors. Official weigh-ins are conducted anywhere from three, and up to 24 hours prior to competition ensuring athletes meet weight requirements (i.e. have ‘made weight’). Fighters commonly aim to compete in weight divisions lower than their day-to-day weight, achieved via chronic and acute manipulations of body mass (BM). Although these manipulations may impair health and absolute performance, their strategic use can improve competitive success. Key considerations are the acute manipulations around weigh-in, which differ in importance, magnitude and methods depending on the requirements of the individual combat sport, and the weigh-in regulations. In particular, the time available for recovery following weigh-in/ before competition will determine what degree of acute BM loss can be implemented and reversed. Increased exercise and restricted food and fluid intake are undertaken to decrease body water and gut contents reducing BM. When taken to the extreme, severe weight making practices can be hazardous and efforts have been made to reduce their prevalence. Indeed some have called for the abolition of these practices altogether. In lieu of adequate strategies to achieve this, and the pragmatic recognition of the likely continuation of these practices as long as regulations allow, this review summarises guidelines for athletes and coaches for manipulating BM and optimising post weigh-in recovery, to achieve better health and performance outcomes across the different Olympic combat sports.
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7. Conclusion
1. Introduction

In the Olympic combat sports of judo, boxing, wrestling, taekwondo and as of 2020 karate; competitors are separated into weight divisions in an attempt to create an ‘even playing field’, reducing size and/or reach differentials between opponents. Prior to competition, athletes have body mass (BM) verified at an official “weigh-in” to ensure they meet the weight requirements of their competitive division; colloquially known as “making weight”. The time interval between weigh-in and competition differs between sports; however a (recovery) period of at least three and up to 24 hours exists among the Olympic combat sports. Most fighters try to take advantage of this scenario using acute weight loss (AWL) strategies in the hours and days before weigh-in to qualify for a division lower than their day-to-day weight, then attempt to reverse the physiological disturbances which accompany AWL during the recovery period (16). Indeed, if “weight making” tactics are sensibly implemented, the opportunities for recovery are adequate and competition regulations do not prohibit the practice, it might be seen as a pragmatic way to optimise competiveness. However, in the absence of these characteristics, AWL can impair performance and health (16, 23), and perhaps be viewed as against the spirit of sport (33). Additionally, severe health consequences may arise; including death, which occurred in 1997 when three wrestlers succumbed to cardiorespiratory arrest following extreme AWL practices (28).

Although some have called for the cessation of AWL altogether (33) another more pragmatic approach is to educate athletes about safer practices around AWL and recovery to reduce the potential health risks and performance decrements. These efforts are warranted given the fact the majority of athletes do not source information from educated nutrition professionals; instead relying on coaches, trainers and other athletes (15). Additionally, aside from deriving (real or perceived) physical advantages, many athletes engaging in AWL report increased feelings of self-confidence, focus, discipline and professionalism among other attributes, thus
AWL is often seen as a key part of combat sport (45). We have previously reviewed various elements of AWL (113); Table 8.1 presents a summary of various AWL strategies and their associated benefits and drawbacks. The aim of the present paper is to apply these themes to the specific conditions of Olympic combat sports and provide guidance for the post weigh-in recovery period. For detailed discussion on AWL, performance effects and mechanisms, readers are directed to previous reviews on this topic (16, 23, 113).

The use of additional un-researched and potentially hazardous and banned methods to achieve AWL, such as diuretics, laxatives, ‘water loading’ etc. is noted (13, 15, 113, 124) however this will not be discussed. Further, as a recent addition to the Olympic program, Karate has received little investigation relative to other Olympic combat sports, thus will not constitute a focus of this review; we will provide specific guidelines for the pre 2020 Olympic combat sports. However, given the similarities between karate and taekwondo in regards to the scoring system, anthropometry of elite athletes, physiological demands of the sports (6, 188) and the weigh-in time frames (taekwondo utilises a day before competition weigh-in and karate usually implements the same; however to our knowledge this has not been confirmed for Olympic karate competition) at this stage karate athletes would benefit from following guidelines aimed at taekwondo athletes. In the future, specific guidelines for karate may be warranted and could be better constructed following additional research examining how AWL and anthropometry relates to Olympic karate performance.
<table>
<thead>
<tr>
<th>Acute weight loss method</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gut content manipulation</td>
<td>Laxative / bowel preparation use</td>
<td>• Loss of ~1-2%BM in &lt;1d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decreased cardiovascular exercise capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Body water loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Electrolyte imbalances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decreased energy intake</td>
</tr>
<tr>
<td>Food restriction</td>
<td></td>
<td>• Decreased satriety</td>
</tr>
<tr>
<td>Fibre restriction</td>
<td></td>
<td>• Empty bowel similarly to bowel prep in 2-7d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Minimal effect on acute nutritional status or performance</td>
</tr>
<tr>
<td>Body water manipulation</td>
<td>Moderate dehydration (≥3% BM loss)</td>
<td>• Largest manipulable component of BM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• May be difficult to restore losses if competing same day as weigh-in</td>
</tr>
<tr>
<td></td>
<td>Mild dehydration (≤3% BM loss)</td>
<td>• Quickly and easily achieved in 1-3h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can restore fluid balance in ≤4 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decreased heat tolerance, aerobic capacity, buffering capacity etc. if not replaced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Athlete may require aggressive hydration recovery plan if competing on same day as weigh-in</td>
</tr>
<tr>
<td>Fluid restriction</td>
<td></td>
<td>• Increased thirst sensation during restriction period</td>
</tr>
<tr>
<td>Glycogen depletion (low carbohydrate intake + glycogen depleting training)</td>
<td>• Loss of ~2%BM in 7d</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maintain strength and power for short efforts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduction in anaerobic performance lasting ~5min if not replaced post weigh-in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Athlete will require aggressive carbohydrate recovery plan if competing on same day as weigh-in</td>
</tr>
<tr>
<td>Sweating methods</td>
<td>Active sweating (exercise induced)</td>
<td>• Can be easily incorporated into existing training sessions before weigh-in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maintain plasma volume to a greater degree than thermoregulatory sweating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Additional exercise may induce fatigue/soreness if athlete is unaccustomed to specific exercise modality / volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High intensity exercise can impact on gastric emptying/GI distress</td>
</tr>
<tr>
<td></td>
<td>Passive sweating (thermoregulatory, i.e. sauna, hot bath, heated rooms etc.)</td>
<td>• Relatively easy method of weight loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• May relax athlete / improve mood etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Preferential loss of fluid from plasma</td>
</tr>
</tbody>
</table>
2. General overview of acceptable practices of acute weight loss

Fighters commonly lose $\geq 5\%$ BM in the week prior to weigh-in (16). Although there is indirect evidence (correlations between post weigh-in weight re-gain and competition success) suggesting these practices do enhance competitiveness (46, 138) they are sub-optimal in terms of health and performance. While we acknowledge there is no single ‘ideal’ AWL target, a key concept of this paper is the pragmatic recognition, under some conditions, AWL of 5-8% BM with an acceptably small impact on health and performance may be possible. These conditions include the athlete’s full awareness of inherent risks and avoidance of practices banned by the rules governing sport. The starting point prior to AWL should represent BM associated with a fully hydrated, well-nourished state; offering plenty of opportunity for meaningful manipulation of gut content and body water. Further caveats include an available recovery period allowing refuelling and rehydration, and the position that AWL efforts represent a short-term departure from a sound nutrition plan. We note this range represents the upper tolerable limit of weight making rather than a goal, and the upper limit be reduced to 5% BM when shorter recovery periods following weigh-in exist.

Athletes’ weight making plans should be developed with recognition of the specific requirements/characteristics of their sport and practices that are individually tolerated. The plan should include the timing and type of AWL practices, and the strategies needed to reverse physiological disturbances and optimise competition readiness post weigh-in. To achieve an individually acceptable BM loss with minimal effect on performance decrements, a variety of techniques aimed at emptying the gastrointestinal tract and reducing body water should be combined (113). The adoption of a low fibre diet for 24-96 hours with minimal food weight in the hours before weigh-in will be effective in reducing the weight of gut contents, while enabling the continued consumption of adequate energy and macronutrients leading into weigh-in, thus aiding performance. A temporary reduction in “bound water” may
be assisted by decreasing sodium intake (98), and by depletion of muscle glycogen stores (105). Further fluid losses can be encouraged utilising passive and active sweating techniques, recognising that although dehydration causes performance impairment (23), a recovery period of >12 hours should allow adequate restoration of losses as well as achieve competition fuelling. Shorter recovery periods associated with some combat sports or the requirement for multiple weigh-ins will require a more conservative approach.
3. Combining chronic body mass management with acute weight loss practices

An ideal BM management plan should consider both chronic and acute aspects. Generally, competitive advantages in combat sports are gained from characteristics such as size and strength, power to weight ratio, leverage and reach. Thus fighters will benefit from (1) having a lean physique, maximising active tissue for a given BM and (2) competing in the lightest possible weight division against athletes with inferior characteristics. Nevertheless, differences between sports dictate some specificity within and between groups of fighters, and thus individuality in desired BM manipulations in the short and long term will now be considered. These differences will play a role in determining long term physique management and day-to-day nutrition strategies of the athlete (beyond the scope of this review; readers are directed elsewhere for detailed nutrition guidance relating to chronic BM management (49)), in turn influencing decisions concerning AWL and re-gain following weigh-in. This regain reflects not only the restoration of nutritional and hydration status for competition, but the effect of BM per se on performance.

Possessing greater BM during competition than an opponent may benefit athletes to varying degrees across sports. A simple appreciation of technical differences between grappling and striking sports includes the consideration that judo and wrestling involve the manipulation of an opponent’s BM whereas, in boxing and taekwondo, tactical movements of one’s own BM contribute more to success. Thus the practical differences in BM and strength may be less important in striking sports. Therefore, aside from maximising strength and power at a given BM, grapplers may aim to gain an edge by utilising AWL to qualify for a lower weight division, but, importantly, maximising BM re-gain prior to competition (46, 138). Indeed given sufficient recovery time, athletes can achieve greater BM at the time of competition than even pre AWL (124). This tactic appears to be less important for taekwondo and boxing (48, 128). Rather, those with a lower BMI (i.e. greater height for a given BM) in taekwondo
show increased speed, speed endurance and flexibility relative to more heavily built athletes (169). Further, data collected at the Olympic Games correlates greater height and lower BMI with competitive success (170). Currently, determining anthropometric ideals for boxing is difficult. Indeed boxing allows for a number of different successful fighting styles, each relying to varying degrees on different physique and fitness traits (189). Hypothetically, a more powerful boxer may benefit from manipulating BMI to allow increased BMI post weigh-in whereas another boxer may utilise BMI manipulations to achieve more height and range. Some have even argued height rather than weight should be used to determine competitive divisions in striking sports (12).

Ultimately, weight making strategies, including the magnitude of BMI manipulation and the strategies used to achieve and reverse it, involve decision-making around a complex set of factors. However, considerations of performance requirements of individual sports, and the logistics of weigh-in and competition may lead to differences in approach between sports. Sports-specific considerations are summarised in Table 8.2.
### Table 8.2 Sport specific chronic body mass management considerations, suggest use and methods of acute weight loss and post weigh-in nutrition recommendations

<table>
<thead>
<tr>
<th>Sport / Weigh-in regulations</th>
<th>Acute on chronic body mass management considerations</th>
<th>Appropriate acute weight loss methods</th>
<th>Recovery / competition preparation Nutrition recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taekwondo</td>
<td>• Height and limb length likely beneficial</td>
<td>• Low fibre diet</td>
<td>• Restore fluid balance</td>
</tr>
<tr>
<td></td>
<td>• Day before competition weigh-in</td>
<td>• Fluid restriction</td>
<td>o drink 150% of lost fluid distributed between weigh-in and sleep time</td>
</tr>
<tr>
<td></td>
<td>• Increased BM likely not beneficial</td>
<td>• Passive sweating</td>
<td>Replenish glycogen stores if utilised low carbohydrate diet (at least to a moderate level)</td>
</tr>
<tr>
<td></td>
<td>• Athletes should utilise chronic and acute weight loss in order to qualify for lower weight divisions where they gain height/reach advantage</td>
<td>• Active sweating (being mindful of possible fatigue)</td>
<td>o ≥5-10g/kg CHO post weigh-in prior to sleep time</td>
</tr>
<tr>
<td></td>
<td>• Maintaining BM above weight division only to enable height/reach advantage over opponent</td>
<td>• Glycogen depletion</td>
<td>Be mindful of fibre intake following low residue diet</td>
</tr>
<tr>
<td>Wrestling</td>
<td>• Increased BM + strength and power likely beneficial</td>
<td>• Low fibre diet</td>
<td>Provide high carbohydrate availability day of competition</td>
</tr>
<tr>
<td></td>
<td>• Day before competition weigh-in</td>
<td>• Fluid restriction</td>
<td>o ≥2 g/CHO/kg in morning meal (3-4 hours pre competition)</td>
</tr>
<tr>
<td></td>
<td>• No additional weigh-in</td>
<td>• Passive sweating</td>
<td>Utilise carbohydrate mouth rinse prior to and in between successive bouts</td>
</tr>
<tr>
<td></td>
<td>• All fights completed in one day</td>
<td>• Active sweating (being mindful of possible fatigue)</td>
<td>Priority: support performance and regain as much BM as possible whilst minimising GI distress</td>
</tr>
<tr>
<td>Judo</td>
<td>• Increased BM + strength and power likely beneficial</td>
<td>• Glycogen depletion</td>
<td>• Restore fluid balance</td>
</tr>
<tr>
<td></td>
<td>• Evening before competition weigh-in</td>
<td></td>
<td>o drink 150% of lost fluid distributed between weigh-in and sleep time</td>
</tr>
<tr>
<td></td>
<td>• Random weight checks morning of competition prohibiting weight gain of &gt;5% above weight division</td>
<td></td>
<td>Replenish/maximise glycogen stores if utilised low carbohydrate diet</td>
</tr>
<tr>
<td></td>
<td>• All fights completed in one day</td>
<td></td>
<td>o ≥7-10/kg CHO post weigh-in prior to sleep time</td>
</tr>
<tr>
<td>Boxing</td>
<td>• General weigh-in first day of competition for all athletes</td>
<td></td>
<td>Be mindful of fibre intake following low residue diet</td>
</tr>
<tr>
<td></td>
<td>• Additional weigh-in each morning for athletes competing that day</td>
<td></td>
<td>Provide high carbohydrate availability day of competition</td>
</tr>
<tr>
<td></td>
<td>• Successive bouts on separate days</td>
<td></td>
<td>o ≥2 g/CHO/kg in morning meal (3-4 hours pre competition)</td>
</tr>
<tr>
<td></td>
<td>• Effect of increased BM and anthropometric qualities on performance unclear</td>
<td></td>
<td>Utilise carbohydrate mouth rinse prior to and in between successive bouts</td>
</tr>
<tr>
<td></td>
<td>• Coaches and athletes to determine if acute weight loss to enable height/reach or BM advantage over opponent is suitable based on boxer ‘style’ and analysis of competitive environment</td>
<td>• Low fibre diet</td>
<td>Priority: support performance and make weight on successive days</td>
</tr>
<tr>
<td></td>
<td>• Maintain BM &lt;5% above weight division, 1 w from competition</td>
<td>• Fluid restriction</td>
<td>• Restore fluid balance</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td>• Passive sweating</td>
<td>o drink 150% of lost fluid if sufficient is available post weigh-in pre-fight without causing GI distress or impacting on competition preparation</td>
</tr>
<tr>
<td></td>
<td>• Maintain BM 5-6% above weight division, 1 w from competition</td>
<td>• Active sweating (being mindful of possible fatigue)</td>
<td>o if body water reduction required for subsequent weigh-in the next day, limit fluid and sodium post bout, monitoring BM and use sweating methods before bed/morning of weigh-in</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td>• Glycogen depletion</td>
<td>o if subsequent weigh-in ≥36 hr, restore fluid balance post bout, use fluid restriction 24 h pre weigh-in and sweating method night before/ morning of weigh-in</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td>• Passive sweating/ glycogen depletion</td>
<td>Continue to limit fibre intake following low residue diet</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td>used only if necessary</td>
<td>Consume low weight high energy high carbohydrate foods to minimise gut content gain in mass</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td></td>
<td>Provide high carbohydrate availability day of competition</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td></td>
<td>o ≥2 g/CHO/kg in morning meal (3-4 hours pre competition)</td>
</tr>
<tr>
<td></td>
<td>• Utilise acute weight manipulation to qualify for lower weight divisions and maximise weight gain post weigh-in</td>
<td></td>
<td>Utilise carbohydrate mouth rinse and caffeine prior to bout</td>
</tr>
</tbody>
</table>

### Note
- **Acute on chronic body mass management considerations**
  - **Day before competition weigh-in**
  - **No additional weigh-in**
  - **All fights completed in one day**
- **Appropriate acute weight loss methods**
  - **Low fibre diet**
  - **Fluid restriction**
  - **Passive sweating**
  - **Active sweating**
  - **Glycogen depletion**
- **Recovery / competition preparation Nutrition recommendation**
  - **Priority: support performance**
  - **Priority: support performance and regain as much BM as possible whilst minimising GI distress**
  - **Priority: support performance and make weight on successive days**
4. Recovery from acute weight loss

The benefit derived from any weight making plan will only be realised if an athlete is able to minimise impacts associated with AWL by reversing associated physiological disturbances. Key considerations include; rehydration, glycogen restoration and the management of gastrointestinal distress following dietary alterations pre weigh-in.

4.1 Rehydration

Although effective in lowering BM, reductions in total body water impair performance in various ways according to characteristics such as the magnitude, method and source of the water loss. Impaired aerobic endurance following dehydration is well documented, however strength and power decrements (generally of greater relevance to combat sports) are less evident (23). Nevertheless, detectable effects on motor skills, cognitive performance and sports specific movement patterns occur following even 2% BM loss (23, 190). Thus, in theory, fighters should aim to restore fluid losses to within ~2% of “pre-hypohydration” BM. Challenges to this goal include available recovery time and difficulty in identifying the true magnitude of hypohydration since, the dissociation between overall BM change and hydration status may be significant. Adequate opportunities for recovery following moderate hypohydration are likely when weigh-ins are held the day before competition. However, this is not the case for boxers weighing-in the morning of competition. Furthermore, successful progression through a tournament requires repeated morning weigh-ins. Since, repeatedly shifting large fluid volumes is not advised, boxers should chronically manage BM to prevent the need to lose >3% BM via dehydration to make weight.

To be incorporated into the body water pool, fluid must be consumed, emptied from the stomach, and absorbed from the small intestine into the bloodstream. These activities are
affected by the volume and composition of fluid, and the consumption rate (191). At rest, gastric emptying is most influenced by the energy density (greater density slows emptying) and volume of fluid in the stomach, with smaller effects coming from changes in pH and osmolality (192). There is no active transport mechanism facilitating water intestinal absorption, thus fluid will cross the intestinal mucosa in either direction following an osmotic gradient. Therefore fluid osmolality relative to plasma becomes important in this aspect also (192). Also relevant to combat sports is the delayed gastric emptying following high intensity exercise (193), thus lower intensity exercise is the preferred active sweating technique to achieve dehydration. Further, hypohydration >3% BM tends to slow gastric emptying further (194).

Although individual variation occurs, increased gastric volume speeds gastric emptying, plateauing at ~600mL and volumes >1000mL potentially slow emptying (195, 196). Thus fighters should consume an initial bolus of ~600-900mL (~600mL immediately following weigh-in if dehydration is >3% BM) with additional boluses at regular intervals to maintain increased gastric volume. Strategies enhancing rehydration rate increase in importance as the magnitude of hypohydration increases and duration of the recovery period decreases. General sports nutrition recommendations for rehydration suggest 125-150% of the fluid deficit needs to be consumed (post dehydrating activities) to compensate for continued urine losses (191, 197). Such advice may be difficult to implement in many AWL scenarios since the true fluid deficit may be unknown (e.g. ‘non-fluid’ AWL may confound the typical use of BM changes in estimating hypohydration) and large fluid volumes may be impractical to consume during limited recovery time (e.g. 3-4 hours often occurring in boxing).

Thermoregulatory and/or exercise-induced sweat losses incur the loss of electrolytes, primarily sodium and chloride (191), thus replacement of these electrolytes is needed to allow restoration of plasma osmolality and volume. As far back as 1974, Dill and Costill reported
consumption of low sodium fluids equivalent to 200% of sweat losses did not prevent a fluid deficit following 2 hours of ongoing urine losses, whereas consumption of 150% of a drink containing 61 mmol/l sodium sufficiently promoted a positive fluid balance (198). Sweat sodium concentrations typically may range from ~20-80 mmol/l (197), thus make prescribing an ‘ideal’ sodium concentration difficult. However, fluid sodium content correlates with fluid retention; due to both the replacement of electrolytes and effects on intestinal absorption (192). Electrolyte replacement occurs following both the consumption of salty foods alongside fluids (199) and oral rehydration solutions (ORS) specially manufactured to address dehydration following diarrhoea/vomiting. These drinks typically contain 50-90 mmol/l sodium (191, 200), which is considerably higher than standard sports drinks (<30mmol/l sodium). Thus if hypohydration is significant and the recovery period is short, ORS provide a valuable strategy for addressing fluid and electrolyte replacement simultaneously. Lastly; fluid restriction causes a net body water decrease without electrolyte losses (201), thus aggressive replacement of electrolytes is not required, and low(er) sodium fluids such as water or commercial sports drinks will be well retained.

4.2 Glycogen restoration

Persistent engagement in exercise involving glycolytic and carbohydrate-oxidative pathways, alongside low carbohydrate intake, will decrease BM via depletion of muscle glycogen and bound water. Combat sports involve persistent high intensity outputs. Although moderate glycogen stores are unlikely performance limiting, anaerobic exercise lasting ~5min may be impaired following glycogen depletion and performance improvements following glycogen-loading are noted (202). Thus, post weigh-in recovery strategies should include sufficient carbohydrate to restore liver and muscle glycogen in view of competition fuel needs. Furthermore, glycogen derived BM gain (105) may indirectly increase competitive success in
grappling (46, 138). Therefore, if time permits and intake does not interfere with rehydration or gastrointestinal comfort, athletes should aim to replenish glycogen stores.

General recommendations to restore glycogen range from 5-7 g/kg/d for athletes engaged in moderate volume training and up to 7-10 g/kg/d to fully saturate glycogen stores (203). Accounting for tapered training and allowing for potential ‘carbohydrate loading’, a wide post weigh-in recommendation of 5-10 g/kg/d encompasses both goals; providing sufficient competition fuel; and glycogen super-compensation maximising BM gain. Aggressive recommendations may best target grappling athletes, whereas, a more conservative target, moderately restoring glycogen is adequate for boxing and taekwondo. Indeed, in boxing where weigh-ins occur every competition morning of a tournament and recovery time is limited, supercompensation of glycogen stores is neither desirable nor achievable. Therefore, boxers should optimise glycogen restoration over the available recovery time within the constraints of preserving gut comfort prior to competition. Strategies include selecting high glycaemic index carbohydrate (204), with the use of carbohydrate-rich fluids to simultaneously address rehydration targets and reduce the gut discomfort often associated with consuming solid foods close to competition. Added protein to recovery meals/snacks increases glycogen storage when carbohydrate intake is sub-optimal (205). It should be noted, however, hypertonic fluids (e.g. fluids >10% carbohydrate) may slow gastric emptying, slowing rehydration and causing GI distress (206). Intestinal absorption of large amounts of carbohydrate (>60g/h) may be assisted by selecting foods/supplements containing varied carbohydrate sources (i.e. glucose and fructose) to take advantage of multiple gut transport mechanisms (207). Nevertheless, noting the difficulty of aggressive glycogen replacement in boxing scenarios and the potential for low glycogen to compromise performance in multi-day competitions (202), boxers should chronically manage BM to prevent the need to severely restrict carbohydrates pre weigh-in.
4.3 Managing gastrointestinal distress

Post weigh-in intake should ideally recover nutritional status while avoiding GI distress. Of the many dietary modifications used to make weight, the low residue diet (reducing gut contents), is potentially the most benign (113). In contrast to decreased body water and glycogen, decreased gastrointestinal bulk is unlikely to impact performance, providing energy is adequate (113). Therefore, this represents AWL which does not require acute replacement. Indeed, suddenly reintroducing dietary fibre slows gastric emptying and absorption of nutrients (208) and may produce discomfort (209), impairing competition performance directly and indirectly. Thus limiting, or at least not over-eating, fibre-rich foods post weigh-in is logical; particularly for boxers when the recovery period is limited, and multiple weigh-ins occur.
5. Pre-competition nutrition

Achieving recovery goals following AWL several hours before competition is desirable, allowing an athlete to shift their focus to traditional pre-competition practices. While there is some overlap between these goals, pre-competition plans in most sports involve a “fine tuning” of nutritional status rather than aggressive reversal of sub-optimal nutrition status. In addition, competition nutrition strategies often include supplement use, manipulation of gut comfort for high-intensity exercise, and the pursuit of comfortable and familiar routines or rituals. When post weigh-in recovery time is limited, integrating these two themes can be challenging. We have previously advised when these challenges are maximised (i.e. when recovery time is short), the magnitude of AWL should decrease reducing the conflict.

Improving carbohydrate availability in the hours before exercise is an evidence-based practice improving performance in endurance sports (210) and emerging research suggests similarities for strength/power events involving repeated intense efforts (211, 212). Devising robust pre-fight meal prescriptions is currently difficult (211), however benefits in repeated high intensity efforts have been shown with carbohydrate intakes ≥1g/kg BM in the hours before exercise (212). Although athletes’ preferences and the likelihood of GI distress must be considered, the consumption of easily digested, low-fat, low-fibre and low gas producing carbohydrate-rich choices before and between bouts seems a reasonable target (213). Of course, some fighters concerned with gastrointestinal distress (potentially exacerbated by gut contact during competition) feel unable to consume foods or fluids in the hours pre-event.

Other competition nutrition strategies, potentially beneficial, include caffeine supplementation and “mouth-rinsing” (without ingestion) with a carbohydrate-based solution or food; both of which are known to aide performance during times of low carbohydrate availability (214). Benefits to performance have been found when exposing the mouth and throat for brief but significant periods (~10sec) to carbohydrate; activating regions or
responses in the central nervous system which may increase corticomotor activity and/or reduce perception of effort (215). Improvements have been reported consistently in moderate to high intensity exercise ranging from 30-60 minutes (216, 217) and inconsistently for very short and single efforts (218, 219). Although combat sport competitions are generally shorter than most performance tests displaying positive results, they are generally longer than those finding no benefit. Without specific combat sports data, definite conclusions cannot be reached, however rinsing the mouth for ~10 sec with a sports drink pre-competition is a low risk strategy potentially providing increased drive at a time when athletes may avoid swallowing foods or fluids (215).

Literature regarding the ergogenic effects of caffeine is extensive. Observed improvements include; enhancement of cognitive attributes (alertness, short term recall, reaction time) and performance in endurance and high intensity intermittent sports protocols (220). Of particular relevance is the decreased RPE accompanying caffeine supplementation during high intensity sport (220), as the ability to endure and maintain effort during difficult situations is of paramount importance in combat sports. Additionally, caffeine aides performance when carbohydrate availability is low (214), thus useful for athletes depleting glycogen stores to achieve AWL who are unable or unwilling to ingest sufficient carbohydrate after weigh-in to adequately refuel. Research on combat sports has provided interesting and conflicting findings. One study investigating the effects of 6 mg/kg caffeine following AWL on performance of a ‘Specific Judo Fitness Test’ (a commonly used reliable assessment, sensitive to changes in training status and specific judo fitness (221)) failed to detect an improvement in performance; yet decreased RPE and increased lactate were noted (222). However, another study, using an upper body intermittent sprint protocol (developed to identify progressive power decrements via replication of the demands typical during multiple matches of wrestling competitions (223)), reported negative outcomes; increased heart rate
and lactate concentrations and decreased peak power across trials following 5mg/kg (224). Negative performance effects of caffeine at these doses are rare (220) but not unheard of in the lab setting (225). More combat sports specific research is needed; however, based on wider literature, caffeine at recommended doses is likely to be benign or beneficial. The dose response relationship with caffeine is known to follow a U-shaped curve where mild to moderate doses (3-6mg/kg BM) ingested 60min pre-exercise elicit desirable effects, with increasing doses causing over arousal, anxiety and declines in fine motor control among other attributes (220, 226). As with all nutritional interventions, caffeine should be trialled prior to important competitions.
6. Consolidating post weigh-in recovery and pre-competition preparation

Thus far, issues of chronic BM management, methods of achieving and recovery from AWL, and pre-competition nutrition have been discussed in isolation. In reality, an athlete will likely be preparing for competition concurrent to reversing a fluid deficit, replenishing carbohydrate stores and managing possible GI distress, following months of chronic BM management. Long term planning should identify an ideal weight division, set BM management milestones, and develop routines surrounding AWL/recovery and competition preparation. Preparation and assessment of recovery requirements and access to suitable foods and fluids should be conducted ahead of time, allowing recovery to commence immediately following weigh-in. Table 8.3 details common key factors to be addressed.
### Table 8.3 Key factors across competition phases affecting all combat sport athletes

<table>
<thead>
<tr>
<th>Competition phase</th>
<th>Factors to address</th>
</tr>
</thead>
</table>
| Weeks to months prior to key competition   | • Develop and implement chronic BM management plan  
• Plan, practice and record responses to acute weight loss/ recovery plans at ‘mock weigh-ins’/less important competitions  
• Develop and refine pre-bout nutrition routines around key training sessions/less important competitions  
  o This includes the use of caffeine, carbohydrate mouth rinse and any other supplements (if appropriate) |
| Competition official weigh-in              | • Ensure recovery foods and fluids have been planned and organised prior to official weigh-in  
• Be sure to bring to the official weigh-in venue foods/fluids required for the first hour(s) post weigh-in  
• Have official weight verified as early as possible during the official weigh-in period to allow the longest possible recovery time |
| Post weigh-in                              | • Recovery in the form of rehydration and glycogen restoration should begin immediately following weigh-in  
• Recovery should be completed as early as possible (taking into consideration the timing required for gastric emptying) so as not to impact on a fighter’s ‘routine’ close to competition  
  o For a day before competition weigh-in this means addressing the fluid deficit (consuming 150% of fluid losses) and carbohydrate recovery 5-10g/kg (individualised based on current and required glycogen status/goals) before going to sleep the night prior to competing  
  o For boxers with a same day weigh-in this means achieving the best possible nutritional status prior to beginning pre-competition preparation (taking into consideration athletes preferences/ GI distress concerns) |
| Pre-competition preparation                | • Ideally an athlete should intake ≥1g/kg carbohydrate in the meal 3-4 hours before competition  
• Athletes should adopt pre competition meal / snack patterns similar to those which they would use before an important training session when not making weight and which ‘make them feel good’  
  o This including the avoidance of foods and fluids for a period of time before competition if the athlete prefers  
  o The use of supplements should only occur if thoroughly trialled prior to competition |
| After competition                          | • Reflect on acute weight loss, recovery and competition preparation plan  
• Assess what worked well and what needs adjustment before the next competition |
Due to logistics and cultural practices, fighters commonly select fluids in the immediate post-weigh-in period (up to 30 min and perhaps 60 min). Access to suitable fluids in the weigh-in environment will increase effective recovery time. Noting there may be a conflict between rehydration goals (lower osmolality/energy beverages enhance gastric emptying) and nutrient restoration goals (aggressive carbohydrate and protein targets), fighters may need to make specific decisions regarding nutrition priorities. Immediate ingestion of an ORS may be a suitable choice prioritising rehydration, however milk as a rehydration beverage is also suitable, having been shown to be better retained than sports drinks (227). Further boluses targeting the gastric volume/emptying effect could include sweetened milk to provide protein and carbohydrate simultaneously and thus address additional nutrition goals.

In the second hour of recovery, athletes may desire to begin consuming solid food, with choices that are carbohydrate-rich, yet low in fibre and fat, being suited to promote glycogen storage while lessening potential gastrointestinal distress. Maintaining rehydration strategies throughout this time is important. However, electrolyte-containing beverages may not be needed if water is consumed alongside sodium-rich foods (228). Indeed, net fluid balance 5 hours post-exercise was shown to be greater following consumption of a mixed meal containing 63 mmol sodium relative to a sports drink providing 43 mmol sodium (228). In reality, many common foods are sodium rich and/or salt easily added as a condiment to suitable recovery meals (199). When control of food composition is difficult and/or an athlete does not desire a larger meal, continued consumption of an ORS to address hydration alongside sugar-rich foods or sports foods (gels, sports confectionery, bars) will address carbohydrate requirements. Similarly, commercial sports drinks are a convenient choice for moderate rates of rehydration and refuelling; however with less than optimal sodium, consuming salty snacks alongside sports drinks will further assist fluid retention.
Pro-active strategies for rehydration and glycogen storage should continue until recovery is achieved (e.g. 125-150% of notional fluid deficit is consumed and adequate carbohydrate ingested) or until consumption interferes with competition preparation and/or causes GI distress. Following weigh-in there is a ‘crossover’ time point where priorities shift from recovery to competition (nutritional, mental and physical) preparation. For those weighing-in the day before competition, a logical plan is to achieve recovery goals prior to sleep, allowing competition preparation to take priority the morning of competition. For those weighing in on the morning of competition, identifying this crossover point is more difficult. Athletes should develop a plan that includes well-practiced routines, identified as making them ‘feel good’, preferably focusing on suitable carbohydrate sources and appropriate fluid intakes in the form of familiar foods trialled ahead of competition. Careful planning, trialling and working with a sports nutrition professional can help athletes identify preferred nutrition sources, and a pattern of intake which addresses recovery, promotes performance and addresses superstitions and preferences regarding competition preparation. Table 8.4 details example food and fluid choices/combinations which suit varying nutritional priorities during the post weigh-in/pre-competition period.
### Table 8.4 Example food and fluid choices for the post weigh-in / pre-competition period

<table>
<thead>
<tr>
<th>Nutrition goal</th>
<th>Food and fluid combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rapid fluid (and electrolyte) replacement</strong></td>
<td>• Oral rehydration solution (ORS)</td>
</tr>
<tr>
<td></td>
<td>• Sports drink with high sodium content (≥50mmol/l) and low carbohydrate content (≤5g/L)</td>
</tr>
<tr>
<td></td>
<td>• Low fat milk</td>
</tr>
<tr>
<td><strong>Increasing carbohydrate availability</strong></td>
<td><strong>Snacks</strong></td>
</tr>
<tr>
<td></td>
<td>• Sports drink / sports bars</td>
</tr>
<tr>
<td></td>
<td>• Low fibre breads + honey/jams</td>
</tr>
<tr>
<td></td>
<td>• Lollies/candies</td>
</tr>
<tr>
<td></td>
<td>• Low fibre fruits / tinned fruit</td>
</tr>
<tr>
<td></td>
<td>• Carbohydrate sports bar</td>
</tr>
<tr>
<td></td>
<td>• Cereal bars</td>
</tr>
<tr>
<td></td>
<td>• Low fat yoghurt</td>
</tr>
<tr>
<td><strong>Meals</strong></td>
<td>• Rice dish</td>
</tr>
<tr>
<td></td>
<td>• Pasta /noodle dish</td>
</tr>
<tr>
<td></td>
<td>• Mashed potato / baked potato</td>
</tr>
<tr>
<td></td>
<td>• Low fat desserts/ice cream</td>
</tr>
<tr>
<td></td>
<td>• Pancakes</td>
</tr>
<tr>
<td></td>
<td>• Breakfast cereal</td>
</tr>
<tr>
<td><strong>Fluid and carbohydrate replacement</strong></td>
<td><strong>ORS paired with:</strong></td>
</tr>
<tr>
<td></td>
<td>• Carbohydrate based snacks:</td>
</tr>
<tr>
<td></td>
<td>• Low fibre breads + honey/jams</td>
</tr>
<tr>
<td></td>
<td>• Lollies/candies</td>
</tr>
<tr>
<td></td>
<td>• Low fibre fruits / tinned fruit</td>
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<td></td>
<td>• Sports bars</td>
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<td></td>
<td>• Carbohydrate based meals:</td>
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<td>• Rice dish</td>
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<td></td>
<td>• Low fat desserts/ice cream</td>
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<td></td>
<td>• Pancakes</td>
</tr>
<tr>
<td></td>
<td>• Breakfast cereals</td>
</tr>
<tr>
<td></td>
<td><strong>Sodium containing carbohydrate based snacks:</strong></td>
</tr>
<tr>
<td></td>
<td>• Low fibre breads + salty spreads</td>
</tr>
<tr>
<td></td>
<td>• Pretzel, low fat potato chips, salted popcorn</td>
</tr>
<tr>
<td></td>
<td>• Crackers</td>
</tr>
<tr>
<td></td>
<td>• Rice cakes</td>
</tr>
<tr>
<td></td>
<td><strong>Sodium containing carbohydrate based meals:</strong></td>
</tr>
<tr>
<td></td>
<td>• Rice dish with added salt / soy sauce / oyster sauce etc.</td>
</tr>
<tr>
<td></td>
<td>• Pasta /noodle dish with added salt, canned high sodium sauce etc.</td>
</tr>
<tr>
<td></td>
<td>• Mashed potato / baked potato with added salt / stock powder</td>
</tr>
<tr>
<td></td>
<td>• Low fat flavoured milk drink</td>
</tr>
</tbody>
</table>
7. Conclusion

Optimal nutrition practices for competition vary among Olympic combat sports, and depend on the specific AWL strategies used, the recovery time available, individual preferences and routines around performance nutrition, and the strategic purpose of acute and chronic BM manipulations. Athletes and coaches should educate themselves, trial nutrition strategies ahead of important competitions and continually refine this process to maximise available opportunities within the regulations of their sport. A summary of different considerations between combat sports which take all these considerations into account is provided in Table 8.2.
Chapter 9
SUMMARY AND CONCLUSION
The five studies and two reviews presented in this thesis examined issues relating to acute body mass (BM) management in Olympic combat sports. While prior extensive research has investigated various factors contributing to our understanding of the underlying physiology of acute weight loss and recovery post weigh-in, combat sport athletes’ practices, the relationship between acute weight management and competitive success and how chronic and acute weight management combine leading into competition; the work presented here fills crucial gaps in the literature and consolidates findings into pragmatic recommendations with real world applicability. Specifically, prior to the present thesis; no detailed guidelines on acute weight loss and post weigh-in recovery specific to each combat sport existed. Furthermore, survey data regarding BM management practices of Olympic combat sport athletes was hard to compare due to varying study methodologies, including the timing of survey administration, the level of athletes surveyed and the specific questions asked. Furthermore, the link between acute BM management and competitive success had not been investigated in all sports, an important issue given each has clearly different requirements for success. In addition, detailed body composition data collected using valid, precise measurement techniques on elite combat sport athletes prior to competition was not available, making it difficult to identify appropriate weight classes for individual athletes. Furthermore, the health and performance implications of increasingly popular yet novel methods of weight management remained unexamined, making it difficult to guide practice on these methods. The first published review (chapter one) within this thesis broadly examined literature across a variety of domains, detailing the methods used by athletes, prevalence, performance implications, underlying physiology and practical applications of acute weight loss. By compiling this literature into a succinct review, we were able to systematically investigate and understand the processes involved in acute weight loss and to provide a key resource for those seeking to better understand this phenomenon in the context of combat sports.
Additionally the recommendations and decision tree presented offer a ‘blueprint’ of sorts, guiding nutrition professionals (as well as athletes and coaches alike) in a step-by-step fashion through the nuanced procedures involved in this often misunderstood area of athlete preparation to minimise any health and/or performance implications of unregulated acute weight loss.

Prior to our national survey of combat sport athletes (study one), variations in data collection methods and study participants made it difficult to compare BM management practices between sports. Inconsistencies were evident in the questions asked, the level of athlete questioned, the timing of questioning relative to competition, and the country (and cultural influences) of the athletes, among other variables. Our survey remedied this by utilising a single tool, based predominantly on a previous validated survey (118) and administering this to athletes at top ranking competitions across all Olympic combat sports, within a single country in a standardised manner. Further, the novel methods as well as ‘optimised methods’ of acute weight loss detailed in the review presented in chapter one informed survey questions and data collection in subsequent studies. This allowed us to investigate how athletes’ BM management practices compare with recommendations, as well as gain insight into the use of novel techniques. Issues such as acute weight fluctuations pre and post weigh-in, chronic weight cycling between competitions, and key sources of weight loss information and practices are common across sports. However sport specific differences do exist and support staff should seek to understand these differences so as to deliver more targeted education. For example, boxers tend to favour active over passive dehydration as well as having a greater reliance on chronic weight loss (relative to other athletes), which is in line with recommendations, whereas wrestlers emphasized acute weight loss (despite larger time intervals between competitions, allowing greater opportunities for chronic manipulation of BM) and preferred passive dehydration, relative to other athletes. Therefore support staff
working with these athletes are best to target their efforts assisting boxers with post weigh-in recovery strategies, whereas discussions with wrestlers could potentially focus more on chronic BM management.

Prior to the current body of work, existing studies had examined the relationship between acute BM management and competitive success in taekwondo and wrestling competitions only (46, 48, 52). Study two and three sought to investigate the relationship between acute BM management and competitive success in judo and boxing, thus completing at least a preliminary exploration of the performance implications of acute BM management across Olympic combat sports. The previous investigations into taekwondo and wrestling provided contradictory outcomes (46, 48, 52). This coupled with the lack of judo and boxing data made it difficult to infer the sports specific performance implications of acute BM management. Using weight regain after weigh-in as a surrogate for acute weight loss pre weigh-in, Kazemi and colleagues found no association with competitive success amongst taekwondo athletes (48). A similar response has been reported in the grappling sport of wrestling, although both successful and unsuccessful athletes in the investigation conducted by Horswill et al (52) gained >5% body mass between weigh-in and competition, confirming the practice is common amongst all athletes, irrespective of competitive success. In contrast, Wroble and Moxley identified high school wrestlers with the greatest post weigh-in body mass regain (and thus presumably greatest acute weight loss prior to competition) were more successful (46). Placed in context alongside the work conducted by Horswill and colleagues (52), the case could be made that in less experienced athletes, where skilled performance has not yet been optimised, physical status and weight manipulation contributes more to success than in elite athletes.

The findings from our work confirm that in the Olympic grappling sports of judo and wrestling, acute weight loss pre weigh-in likely provides a competitive edge, whereas in the
Olympic striking sports of boxing and taekwondo this is not the case. One explanation for this lies in the technical differences between striking and grappling. Grappling involves the manipulation of an opponent’s BM and the imposition of one’s own BM on the opponent, whereas striking competitions tend to rely more on the strategic and tactical movement of one’s own BM. Indeed stature (and thus reach) may be more important in striking (12). Lastly, further strengthening our interpretations is a recently published investigation replicating our findings in (professional) boxing (229). Moving forward, researchers should continue to investigate the association between acute weight loss and competitive success; aiming to determine if the link remains among various weight divisions and levels of competition across all Olympic combat sports, including Karate. Additionally the issue of repeated weight making (evident in boxing tournaments) warrants investigation, as it has been shown (in light weight rowers at least) that the physiological and performance effects involved in weight making differ following repeated efforts (24).

Having normative data on successful performers across weight divisions will help to guide athletes in the selection of competitive weight divisions. While a great deal of data has been published looking at body composition profiles of combat sport athletes, the vast majority utilised indirect estimates of body composition such as prediction equations based on skin fold measurements or bio-electrical impedance (6, 8, 132, 135), both known to have poor validity when assessing body composition close to competition where manipulation of body water is common. Thus study four aimed to describe the physique traits of elite combat sport athletes using modern and measurement techniques, the results of which provide indirect insight into their chronic BM management philosophy.

DXA is noted as the preferred body composition assessment method for athletes (161), yet few data existed utilising it to examine combat sport athletes. When DXA has been used, the representative nature of the subjects was questionable and no commentary was offered.
regarding relevance to specific weight divisions (14). Athletes investigated by our group were all of national/international standard and assessed close to competition, representing elite performers in ‘competition shape’. We identified physique trait differences across weight divisions, indicating that heavier athletes typically possess greater relative fat mass and thus could potentially make weight through chronic manipulation in BM alone (avoiding any potential health and/ or performance implications of acute weight loss), increase lean mass within their selected weight division, or even compete in a weight division lower than previously identified. On the other hand, lighter athletes typically possess lean physiques, with many incapable of avoiding acute weight loss strategies in order to meet self-selected weight divisions requirements. This finding was in line with evidence gained in study three which inferred acute weight loss in boxers, revealing greater acute weight loss in those athletes competing in the lighter weight divisions. While these findings have been reported in earlier work (46, 52) our investigation of judo athletes (study two) did not find this. Of note were the significant differences in taekwondo athletes relative to other athletes; in that low BMI, low relative fat and lean mass and a preferential disposition of lower body lean mass was found. This adds to the body of research suggesting an ‘ideal’ body type in taekwondo (6, 9-11) is tall with low body fat while also low in muscle mass relative to stature, likely providing increased reach and thus benefit in competition. Utilising the range of physique trait variables derived from this cohort of elite performers in ‘competition shape’ as reference ranges combined with conclusions regarding the benefit of acute weight loss across sports (study two and three and previous literature), sports nutrition professionals can now work with combat sport athletes to devise realistic and optimised chronic and acute BM management strategies to achieve informed weight category goals.

A wide array of acute weight management practices are utilized by athletes. Recent reports indicate (91, 124) the popularity of ‘water loading’ as a means to increase body water losses
during fluid restriction. We confirmed this, identifying ~40% of Australian Olympic combat sport athletes having used this practice, and subsequently conducted a clinical investigation into its effectiveness and safety (study five). This intervention study provided evidence of the effectiveness of water loading (consuming 100ml kg\(^{-1}\) daily for three days) in the context of athletes hoping to achieve increased acute weight loss, relative to a ‘habitual’ fluid intake (40ml kg\(^{-1}\) daily). No adverse health implications were evident. Furthermore, analysis of hormonal responses combined with established animal model observations suggest the effect of vasopressin on aquaporin 2 channels may explain the increased fluid losses (184-186).

Building upon our work and placing it in context of earlier literature suggesting water loading may alter fluid resorption for as long as three days (187), it is possible that increasing the duration of fluid restriction beyond the ~24 hours utilised in our study would provide further benefit in athletes’ efforts to reduce body water. Indeed it is anecdotally reported that athletes engage in extensively more severe dehydration combined with food restriction in combination with water loading, thus it could be argued that our study lacks ecologically validity. This is of course true however we elected to sacrifice ecological validity in order to isolate the individual effect of the water loading itself. Combining water loading alongside energy and sodium restriction as well as additional dehydration methods may alter the result obtained and potentially increase the risk of negative outcomes. However this remains speculative and an area for future research for those wanting to ‘fine tune’ the real world application of water loading. It should be mentioned that while water loading could aid athletes in their weight making efforts, it is logical to suggest that boxers would benefit less than other athletes from this practice as weigh-ins at boxing tournaments are closer to competition, thus recommended fluid losses are less than for other Olympic combat sports. Furthermore, multiple weigh-ins are required for those who progress throughout a tournament. Therefore any benefit derived from helping an athlete make weight for their first
weigh-in will likely be decreased or lost for subsequent weigh-ins as alterations in fluid resorption in the kidneys presumably return to normal following resumption of fluid intake post weigh-in. It is important to note that athletes wishing to utilise this novel method of acute weight loss seek the support of informed support staff in order to develop a plan which minimises any potential health consequences.

Taking into consideration existing literature, results obtained from the studies presented within this thesis and the physiological requirements and competition/ weigh-in regulations, our final review (chapter eight), provided detailed post weigh-in recovery guidelines specific to each Olympic combat sport. These recommendations were designed to complement the acute weight loss guidelines advocated in chapter two. They provide not only post weigh-in recovery advice, but sport specific suggestions for acute weight loss methods, as well as for what purpose acute or chronic BM manipulations are best to be used to aid competitive success, i.e. grapplers may derive benefit from increased BM itself, whereas taekwondo athletes will benefit from acute BM manipulations if this enables increased height and range within a specified weight division. Lastly, the commentary surrounding pre-competition nutritional preparation including supplement use, provides athletes, coaches and support staff with evidenced based guides to optimising competition nutrition after making weight.

The work presented in this thesis was completed with direct applicability to real life sporting situations in mind. We propose support staff working with Olympic combat sport athletes;

- Utilise the acute BM manipulation/ pre and post weigh-in nutrition recommendations set forth in our published reviews (chapters two and eight) alongside existing work guiding chronic BM management nutrition practices (49).
- Become familiar with the nuanced differences in existing practices across Olympic combat sports (study one), using this to help identify key areas of targeted support.
• Understanding the implications of how acute weight manipulations relate to competitive success (study two and three combined with previous literature (46, 48, 52, 229)).

• Familiarise themselves with reference ranges for lean and fat mass across a range of BM (study four), and from this potentially identify a preferred weight category for individual athletes, taking into consideration both health and performance outcomes.

• Familiarise themselves with the evidence regarding an increasingly popular method of acute weight loss (study five); and stay abreast of emerging evidence supporting or contradicting the use of novel weight loss methods used by athletes.

Adopting these suggestions will ensure support staff are better resourced to deliver evidence based, pragmatic advice regarding acute and chronic body mass management and competition nutrition strategies for Olympic combat sport athletes.

There are some key limitations apparent within the studies presented throughout this thesis. For studies one through to four, the representative nature of the athletes/participants could be questioned. Although every attempt was made to select the highest quality athletes available, the nature of research and the fact that Australian athletes are not among the top combat sport nations in the world, may leave the reader wondering if the conclusions drawn are truly applicable to elite international athletes. Whilst this critique is valid, the survey data in study one reveals many similarities between Australian athletes and previously reported on international athletes. Further, the focus of this thesis was optimising practises in Australian athletes, thus we suggest that subject selection is appropriate. Other limitations include deriving conclusions from cross sectional/observational data, small sample sizes in certain groups and the reliance on self-reported measures. This is somewhat inevitable given the questions we investigated and nature of applied work, however readers need to consider these limitations when basing actions and recommendations on our findings.
This body of work provides the stimulus for various avenues of future research. Research possibilities are essentially endless, however some key areas of focus we suggest include;

- Additional intervention studies examining other novel acute weight loss techniques
- Investigations into different water loading protocols of varying levels of real world representiveness to assess the safety and efficacy of more ecologically valid practices
- Detailed dietary intake studies during training and pre/during competition to assess how athletes current practices align with our recommendations
- Additional intervention studies assessing combat sport specific performance outcomes following nutritional strategies we have suggested based on wider research (i.e. caffeine use and carbohydrate mouth rinsing during competition, low fibre diets and low sodium diets for weight loss etc.)
- Examination of how acute weight management practices may effect sporting performance in other weight category sports as well as sports where power to weight ratio is important for success (i.e. jumping, running, climbing etc.)
- Research to determine the most effective means of communication leading to increased uptake of nutrition advice among combat sport athletes
Chapter 10
REFERENCES


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Chapter 11
APPENDIX

Modified Rapid Weight Loss Questionnaire

Survey tool used in study one
Questionnaire about pre-competition weight cutting in combat sports

Please answer the following questions with as much attention and seriousness as possible

General Information

Name: ____________________________ Todays date: ____________________________

Age (years): ____________________________ Gender (male/female): ____________________________

1. At what age did you start training taekwondo/judo/wrestling/boxing? (years): ____________
2. At what age did you start competing in taekwondo/judo/wrestling/boxing? (years): ____________
3. How much do you weigh? (kg): ____________
4. How tall are you? (m): ____________
5. Please describe your achievements in taekwondo/judo/wrestling/boxing competitions to date (including today):
   Regional or city level competition
   Participitate without winning a medal (   ) Won a medal (   ) Never participated (   )
   State level competition
   Participitate without winning a medal (   ) Won a medal (   ) Never participated (   )
   National level competition
   Participitate without winning a medal (   ) Won a medal (   ) Never participated (   )
   International level competition
   Participitate without winning a medal (   ) Won a medal (   ) Never participated (   )

6. How many times did you compete in the last year (including non-official competitions)? ____________
7. In how many competitions did you win a medal in the last year (including non-official competitions)? ____________
8. How much weight have you lost in the past week? ____________kg - past 2 weeks? ____________kg - past month? ____________kg
9. To lose weight for THIS COMPETITION, did you in the PAST WEEK:
   (   ) sweat by sauna/sweatsuit/bath/shower
   (   ) reduce fluid consumption
   (   ) use exercise to sweat
   (   ) reduce portion sizes
   (   ) skip meals
   (   ) use a low residue/fibre diet

Weight cutting history and diet patterns:

10. Which weight class do you currently compete in?: under ____________kg.
11. Did you change your weight class in the last two years?
    (   ) yes. What weight class did you previous compete in?: under ____________kg.
    (   ) no. I competed in the same weight class for the past 2 years.
12. How much did you weigh in the last taekwondo/judo/wrestling/boxing off season?: ____________kg.
13. Have you ever lost weight in order to compete?
    (   ) yes. (please continue answering the rest of the questionnaire)
    (   ) no. I have never lost weight in order to compete. (thank you for your help, do not answer the rest of the questionnaire).
14. What is the MOST WEIGHT that you have ever cut in order to compete in your career?: ____________kg.
15. How many times did you cut weight to compete in the last season/year?: ____________times.
16. How much weight do you usually cut before competitions?: ____________kg.
17. In how many days do you usually cut weight before competitions?: ____________days
18. At what age did you begin to cut weight for competitions?: ____________years old.
19. How much weight do you usually regain in the week after a competition?: ____________kg/week.
20. 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 and taught you how to lose weight) **(number each bracket)**

1 – not influential  
2- little influential  
3- unsure  
4- some influential  
5- very influential

( ) another taekwondo/judo/wrestling/boxing athlete  
( ) a fellow training partner  
( ) taekwondo/judo/wrestling/boxing coach  
( ) parents  
( ) physician/doctor  
( ) dietitian  
( ) physical trainer  
( ) other. Please explain________________

21. The table below presents several methods to lose weight rapidly. Using the table below, **HOW OFTEN** did you use each of the following method to lose weight before competitions? **(check all items)**

<table>
<thead>
<tr>
<th>Method</th>
<th>Always</th>
<th>Sometimes</th>
<th>Almost never</th>
<th>Never used</th>
<th>I don’t use anymore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradual dieting (losing weight in 2 weeks or more)</td>
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<tr>
<td>Skipping 1 or 2 meals</td>
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<td>Fasting (not eating all day)</td>
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<tr>
<td>Restricting fluids ingestion</td>
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<td>Increased exercise (more than usual)</td>
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<td>Training intentionally in heated training rooms</td>
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<td>Saunas</td>
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<tr>
<td>Training with rubber/plastic suits</td>
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<tr>
<td>Use of rubber/plastic suits during the whole day and/or night (no exercising)</td>
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<td>Spitting</td>
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<td>Laxatives</td>
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<td>Diuretics</td>
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<td>Diet pills</td>
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<tr>
<td>Vommitting</td>
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<td>Low salt diet</td>
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<td>Low residue/fibre diet</td>
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<td>Low weight/high energy food</td>
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<td>Water loading</td>
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<tr>
<td>Sleeping with head tilted downwards</td>
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</tbody>
</table>