Rapid Weight Cutting Strategies for the Strength Athlete

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Abstract

Rapid weight loss (RWL) refers to significant bodyweight reduction over a short duration, typically within 7 days prior to competition. While common in weight-class restricted athletes, RWL may impair performance and alter psychological states, with increased risks of tension, anger, confusion, and disordered eating. Although well-documented in combat sports, research on RWL in weight-class restricted strength athletes (WRSA) remains limited. Given the methodological similarities in RWL across sports despite differing physiological demands, tailored research for WRSA is warranted.

A literature review was conducted on the physiological, psychological, and performance effects of RWL in combat athletes, aiming to inform best practices for WRSA. The review found consensus that RWL impairs physical and mental states and performance, with severity linked to weight lost and recovery post weigh-in (PWI). While PWI windows and sport demands differ, general recommendations such as minimising extreme cuts and prioritising rehydration are applicable to WRSA, though further targeted research is needed, particularly at the elite level.

To assess RWL practices among elite powerlifters, a survey of 64 competitors at the 2018 international powerlifting federation (IPF) World Championships was conducted. 83% reported RWL use, with an average weight loss of 2.9%. Among those reporting reduced training performance, 92% used RWL. Negative psychological effects were reported by 91%. Medal winners were more likely to engage in RWL, losing more body mass (4.1% vs 2.7%) and competing in more meets annually, suggesting better adaptation to RWL practices.

A second survey assessed subjective wellbeing using the Short Recovery and Stress Scale (SRSS) at three time points (7- and 2-days prior, and competition day) in 53 competitors across 2019 and 2022 IPF World Championships. Higher good lift points (GLP) (a bodyweight-strength relative strength coefficient) correlated with better recovery. Greater RWL magnitude predicted worse SRSS scores, with female lifters more negatively impacted, indicating elite powerlifters manage RWL stress variably by sex and competitive calibre.

Following the surveys, a crossover intervention examined the effects and repeatability of a 3-day low-fibre, reduced food volume (LGV) diet at maintenance calories. Participants completed two trials separated by a 3-week washout. A consistent 1.4%–1.7% body mass reduction in both males and females occurred, establishing LGV as a reliable, repeatable RWL method without requiring fibre tracking.

The final crossover study investigated the performance effects of 1.5% dehydration via heat exposure at two time points (AM vs PM) in a repeated measures design. Resistance-trained participants' lower-body strength and power performance declined in both conditions, without time-of-day differences. However, those who first underwent PM dehydration, which may be subjectively easier, exhibited less performance decline, suggesting a potential acclimation or positive expectancy effect. Ballistic push-up performance was unaffected. Thus, lower-body movements are more sensitive to dehydration-induced RWL, but performance losses may be mitigated by prior exposure.

Collectively, these studies establish the prevalence of RWL in elite powerlifting, its psychological and physiological impacts, and assess specific, repeatable strategies for safe weight reduction with minimal performance detriment. Further work should refine RWL methods tailored to WRSA and address sex-specific responses and recovery optimisation.

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List of commonly used abbreviations

1RM: One-repetition maximum

BM: Body mass

BPU: Ballistic push-up

CMJ: Countermovement jump

GLP: Good lift points

IMTP: Isometric mid-thigh pull

IPF: International Powerlifting Federation

LGV: Reduced food volume and low fibre diet

MMA: Mixed martial arts

PD: Passive dehydration

PWI: Post weigh-in

RIR: Repetitions in reserve

RPE: Rating of perceived exertion

RT: Resistance-trained

RWL: Rapid weight loss

SD: Standard deviation

SRSS: Short recovery and stress scale

WIP: Weigh-in period

WRSA: Weight-class restricted strength athlete

Attestation of authorship

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

Kedric Kwan Xue Bin

Co-authored works

In Review

Kwan, K, Helms, ER, King, A
Using the Short Recovery and Stress Scale to Evaluate Changes in Wellbeing and Performance in World Class Powerlifters.
Journal of Sport Sciences

(Contribution of co-authors: Kwan 85%, Helms 7%, King 8%)

Kwan, K, Helms, ER, King, A
A 3-day low fibre diet with macronutrient manipulation induces repeatable, short term weight loss in resistance trained men and women.
Research Quarterly for Exercise and Sport

(Contribution of co-authors: Kwan 85%, Helms 10%, King 5%)

Kwan, K, Helms, ER, King, A, Cross, M, Yang, D
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"Two roads diverged in a wood, and I took the one less travelled by,

And that has made all the difference,

Because the road paved with good intentions, caffeine, late nights

and a pandemic will certainly change your life"

Ethics approval

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for the thesis research on:

- 24 May 2022 AUTEC reference number 18/161 (Chapters 3 and 4)
- 8 September 2021 AUTEC reference number 20/203 (Chapters 5 and 6)

Chapter 1 Introduction

Section 1: Background and rationale

RWL is a practice commonly used in weight-class restricted sports, ranging from combat sports such as wrestling, boxing, mixed martial arts (MMA), and strength sports such powerlifting, weightlifting and strongman [1, 2]. Athletes aim to lose a significant amount of weight in a short period of time to qualify for a lower weight class. Methods of RWL are largely differentiated into two categories such as methods that induce body mass (BM) loss through dehydration and methods that induce BM loss without dehydration. The former typically includes fluid manipulation [3] or sweating [4] (passive or active) while the latter consists of reducing food volume either through calorie, fibre or food volume restriction [5]. Athletes may employ one or more methods depending on the total percentage BM loss required and RWL strategies that consist of multiple methods can be viewed as a more aggressive. While weight cutting can give athletes a perceived advantage by allowing them to compete against lighter or smaller opponents, it also poses substantial risks to health, performance, and overall well-being [6, 7].

Athletes often employ strategies such as water loading, sauna sessions, reduced carbohydrate intake, and minimal food consumption in the days prior and/or right up to weigh-ins [8]. The intention of RWL is to reduce body water, food mass and muscle glycogen (and to a lesser degree fat mass), which collectively can drastically lower body weight. While athletes effectively use these strategies to make weight, it comes at the potential cost of increased fatigue, decreased mental sharpness and performance, and in some cases death [9, 10]. The degree of negative impact is dependent on the magnitude of BM loss, with larger magnitudes of weight loss leading to larger negative impacts [11, 12]. However, with moderate magnitudes of BM loss, not exceeding 5%, negative impacts can be mitigated PWI with proper rehydration and refuelling [13]. Athletes usually attempt to regain lost weight by rehydrating and eating nutrient-dense foods to restore energy PWI. An important factor to consider is that PWI periods vary across sports, competitive levels and age groups. A shorter time frame often limits full recovery, impacting physical and mental readiness, and performance on competition day, with 24 hours being insufficient in some instances for restoring performance to baseline [14]. Due to these differences, coaches or athletes should adopt tailored RWL approaches to minimise negative health and performance impacts and to increase the likelihood of higher performance.

Current research primarily focuses on combat sports, but athletes who practice RWL extend beyond combat sports [15]. The growth of weight-class-restricted sports, driven by increased broadcasting of large-scale events such as the SBD Sheffield event, World's Strongest Man, inclusion of powerlifting in the World Games, and weightlifting in the Olympics, has led to greater participation in these sports [16]. For WRSA, making weight is an inherent part of competition. Over 80% of powerlifters engage in some form of RWL regardless of competitive status [2, 17], indicating the widespread practice of RWL; a trend also seen in combat sports [18]. Due to the lack of specific research on RWL in WRSA, coaches often extrapolate findings from combat sports to inform their practices with WRSA. However, because of differences in energy demands, PWI periods, and sport specific skills between combat athletes and WRSA, combat sport research findings may be limited in direct application [19, 20].

In light of this, the ethics and safety of RWL have come under scrutiny, with research scientists and sports organizations debating regulations to reduce the practice's dangers [21]. Despite the risks, many athletes continue to rely on RWL as an essential component of their preparation [22], highlighting the complex balance between gaining a competitive advantage and health considerations in weight-class sports.

Section 2: Purpose of the research

The overarching aim of this thesis was to expand the knowledge on RWL strategies specifically for the WRSA and to answer these questions:

1. What current evidence exists regarding RWL in the literature?

    a. What are common magnitudes of BM loss, RWL methods and health and performance impacts when performing RWL?
    b. To what degree can findings in combat sports athletes be extrapolated to WRSA?
2. What RWL methods do elite powerlifters use and how much weight do they lose?
    a. What is the percentage of BM loss in elite powerlifters competing at the World Championship level?
    b. What are the most common RWL methods used to induce that BM loss in these lifters?
    c. Does implementing RWL impact the competitive performance of these powerlifters?
3. What is the relationship between RWL and subjective measures of wellness in elite powerlifters competing at the World Championships?
    a. How do validated subjective measures change in 7 days leading to weigh-ins in powerlifters engaging in RWL?
    b. Is there a relationship between the change in bodyweight, subjective wellness, competitive level, and biological sex in these lifters?
    c. Hypothesis: There may be a relationship between SRSS category scores and certain descriptive factors, such as body weight loss, time, and the competitive level of the powerlifter.

4. Is LGV across 3 days a viable and reliable method of RWL?
    a. What is the percentage of BM loss employing a LGV diet across 3 days?
    b. Does a LGV diet produce repeatable weight loss within subjects, and is there any influence of biological sex?
    c. Hypothesis: a 3-day LGV diet would result in significant BM losses, that the losses would be similar between crossover arms, similar between males and females, and be slightly higher (0.8-1% of BM) than the BM losses reported in prior research when a low fibre diet was used in isolation.

5. What are the impacts of dehydration via heat exposure at different time points relative to performance testing on upper and lower body strength and power?
    a. How are upper and lower body strength and power affected by three different states of hydration (baseline, dehydrated, rehydrated)?
    b. Does the timing of dehydration (the night prior to or the morning immediately before testing) influence upper and lower body strength and power?
    c. Hypothesis: Dehydration via heat exposure would negatively impact strength and power performance, but that dehydration in the evening would impact performance less than dehydration in the morning due to the further proximity of heat stress to testing.

Section 3: Significance of the thesis

RWL is defined as a drastic reduction in bodyweight in a relatively short period of time, usually in the 7 days prior to competition [23, 24]. Widely employed in weight-class restricted sports, particularly in combat sports, recent research also indicates RWL is frequently used by WRSA in powerlifting [2], weightlifting [25] and possibly strongman. The benefits reported by combat athletes range from dominance over competitors and a perceived edge in performance [26]. However, downsides such as increased fatigue, lack of vigour, poorer mental focus and a decrease in performance have also been reported [27, 28]. Thus, employing RWL requires careful consideration. Factors such as PWI, rehydration and refuelling protocols, and the specific demand of the sport must be considered when engaging in RWL.

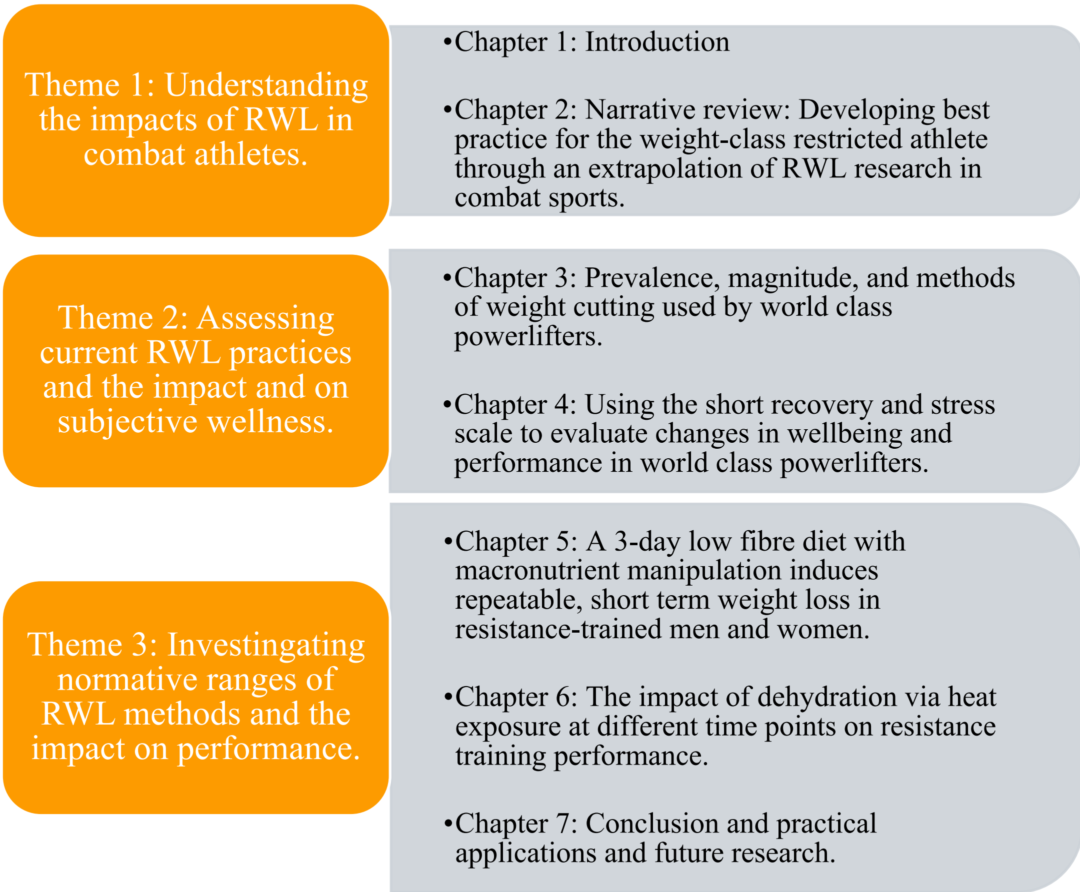
Of the RWL research that exists, a majority of studies were done in combat athletes with only a single survey [2] of powerlifters and weightlifters [29] existing prior to the present work, and fewer, limited experimental studies on the impact of some RWL methods on strength, only using the bench press [30], making best practices for the WRSA ambiguous. Currently, most studies do not provide normative ranges of BM loss for individual RWL methods as most research in combat sport simply requires athletes to lose a set amount of BM, with the RWL methods self-selected [31]. Therefore, this thesis aims to address these gaps in the literature by evaluating RWL practice similarities among combat athletes and WRSA, followed by documenting the effects of, and empirically testing differences after specific RWL strategies in WRSA-relevant performance. Collectively, this research will contribute to the body of evidence necessary to help develop RWL best practice guidelines for the WRSA.

Section 4: Structure of the thesis

This thesis is presented as a "thesis by publication"; inclusive of journal-style articles (referred to by AUT as 'Format 2') excepting the introduction, literature review, and discussion chapters. It is organised into three sections (Figure 1-1). The first section introduces the thesis (Chapter 1) and reviews the current literature on RWL in combat sports and how that may apply to the WRSA (Chapter 2). The second section presents data from two surveys, the first of which examined the prevalence, magnitude, and methods of RWL in world class powerlifters (Chapter 3) while the second investigated changes in subjective wellness across 7 days leading up to weigh-ins in world class powerlifters engaging in RWL (Chapter 4). The third and final section of this thesis established the magnitude weight loss when performing a LGV diet (Chapter 5) and also investigated of the effects of passive dehydration (PD) via heat exposure at different time points on WRSA relevant performance (Chapter 6). The thesis concludes with a discussion which integrates the existing literature with the present data to inform RWL best practices for the WRSA and providing recommendations for related future research (Chapter 7).

Chapters 3, 4, 5, and 6 are in various stages of publication in peer-reviewed journals. Chapter 3 has been published by the Journal of Strength and Conditioning Research, Chapters 4 has been submitted to the European Journal of Sport Sciences and is in peer review, Chapter 5 has been submitted to Journal of Sport Sciences and Chapter 6 has been submitted to the Journal of Sports and Exercise Science and is in peer review. Consequently, the chapters are presented in the format of the respective journal, thus, some inherent repetition between these chapters (most notably in their introductions) and between these chapters and the final discussion is unavoidable. Finally, the COVID-19 pandemic and subsequent lockdowns in New Zealand resulted in significant interference with data collection, resulting in an extended timeline, lower sample sizes than initially intended, and fewer experimental assessments of RWL strategies. However, with timeline extensions and modifications to the original PhD plan, enough high quality data was eventually collected to surpass the doctoral thesis standards.

Figure 1-1 Thesis structure



Chapter 2 Literature review

Prelude

RWL is widely practised in combat sports with varying reported magnitudes of BM loss and RWL methods. There is, however, no critical synthesis that reviews and explores RWL for the WRSA. Given the bioenergetic demands, technical skill and PWI period differences between combat athletes and WRSA, such a review is needed. Indeed, important aspects related to RWL can vary greatly between combat and WRSA, such as the magnitude of BM lost, methods used to induce RWL and PWI rehydration and refuelling approaches. These distinctions make the current available research on RWL in combat athletes limited for implementation among WRSA. Thus, the following review served as the first step to better inform RWL practice for WRSA, by evaluating the similarities and differences between combat and strength sport RWL methods, as well as the limitations of the current data to determine what can and cannot be extrapolated to the WRSA.

Section 1: Introduction

Powerlifting is a weight class-restricted strength sport in which competitors aim to lift the heaviest load across three lifts: the squat, the bench press, and the deadlift. The competitor with the largest total load lifted in his or her weight class wins. Like combat sports, powerlifting is a weight class sport and "making weight" (weighing in below the maximum weight threshold for the respective weight class) is a crucial component. While making weight is highly individual from athlete to athlete, the most common method involves employing a gradual diet followed by RWL [2]. Gradual dieting through a sustained calorie deficit results in the loss of body fat and, in some cases, lean mass [32]. This is in contrast with RWL, which is usually performed across a shorter period (5-7 days before competition) with the goal of reducing body weight through the manipulation of body water content, stored glycogen and/or gut mass [33]. However, there are instances when the gradual diet is extended into the RWL phase, in the hope of achieving more weight loss. Since the process of making weight in powerlifting is a practice shared and arguably influenced by combat sports, it is no coincidence that similar methods are employed by combat athletes and powerlifters to make weight

[17]. Despite the similarities to and influence from combat sports, combat athletes lose larger magnitudes of BM (4-8%) because most combat sports allow a longer weigh-in period (WIP) for rehydration and refuelling. Notably, the longer the WIP, the more weight athletes attempt to lose [11]. However, the WIP for the largest internationally recognised strength sports (e.g., the IPF and the International Weightlifting Federation [IWF]) is no longer than 2 hours [34, 35], which limits strength athletes' total weight loss.

Performance indicators vary among combat sports; thus, the impact of RWL on performance is inconclusive and may be sport specific. For example, Judo athletes may benefit more from RWL compared to boxers as, compared to boxing which is more skill/striking dependent [36], Judo performance is more influenced by BM [19]. Regardless, RWL in combat athletes is widespread. Strength sport performance is arguably more one-dimensional, at least in powerlifting and weightlifting, based primarily on maximal force production [37, 38], although strongman/woman competitors may also perform events which include multiple reps and/or distance/time trials [38]. While most combat athletes attempt to weigh in at the upper end of their specific weight class to gain an advantage over lighter opponents [39], powerlifters often train at a body weight slightly above their weight class cut-off, sustaining a higher calorie intake to accrue muscle mass to maximise training performance [40]. This practice is supported empirically as muscle hypertrophy is related to powerlifting performance [41], and a calorie deficit can impair lean mass gains [42]. Hence, performing RWL may allow a strength athlete to train at a higher weight, spending more time at a higher energy intake and therefore, carry more muscle mass.

Despite the potential benefits of RWL, excessive RWL can impair exercise performance [43], increase injury risk [44], negatively impact psychology [45], and in extreme cases, cause death [10]. While these risks and negative outcomes have been observed in combat sports, similar research has not been conducted in strength athletes, and thus, similar results cannot be extrapolated with full certainty. Preliminary studies measuring bench press performance indicate dehydration can reduce maximum strength [4], but this is reversed when adequately hydrated. Adding complexity, different methods of dehydration (passive versus active) may impact strength differently [46], and while not as common in strength sports, dehydration through heat exposure is utilised in combat sports [11], which may also impact maximum strength, although data are mixed [47, 48]. Currently, there are many unknowns regarding RWL best practice for strength athletes, but the prevalence of RWL in powerlifters is high, with ~80% performing some form regardless of competitive level [2]. Thus, a more thorough understanding of RWL risks in strength sport is needed, which will help inform RWL best practices to increase safety while minimising decrements in performance.

The current body of evidence specifically pertaining to RWL in strength athletes is lacking. [29] surveys conducted in powerlifters [2, 15, 17] and one in weightlifters ([29]) exist, while experimental work has only evaluated the bench press as an indicator for strength [4]. Hence, the primary focus of this review is to first identify the efficacy of various RWL methods for acute BM loss as well as the potential negative impacts that may result from them in the combat sport literature, with the perspective of how they may apply to strength sport. Thus, secondly, this review will identify the similarities and differences between combat and strength athletes, including differences in energy demands and systems, nutritional recovery strategies, PWI window time frames, effects of dehydration on specific performance factors, and more, to extrapolate RWL best practices from the combat sport literature, for the strength athlete. Therefore, the following RWL recommendations serve to preliminarily inform best practice as a precursor to future work as the body of evidence specifically on strength athletes grows.

Section 2: Methods

This narrative review is a review of reviews; the search was limited to “reviews” in PubMed, SPORTDiscus, Scopus, and CINAHL electronic databases, which were searched online in addition to backward citation tracking and subsequent manual searching with experimental search string combinations to ensure no reviews were missed. The search string: * ("making weight" OR "weight management" OR "weight cutting" OR "weight reduction" OR "weight manipulation" OR "weight control" OR "rapid weight cutting" OR "RWL") AND ("combat sports" OR "combat athletes" OR "martial arts" OR "boxing" OR "wrestling" OR "mixed martial arts" OR "MMA" OR "judo" OR "taekwondo" OR "karate") * was used for initial selection of manuscripts while limiting database results to peer-reviewed reviews of human subjects in English. Once all manuscript records were obtained, initial screening consisted of: (i) screening for duplicates; (ii) screening titles for relevance; (iii) screening abstracts for relevance; (iv) screening full papers for inclusion criteria; and (v) reviewing references of the included papers for additional relevant publications not located previously. For a review to be included it must have either discussed 1) total weight loss 2) RWL methods used by athletes/participants or 3) the impact of RWL on physiological, psychological, or performance measures from intervention studies, or retrospectively via survey. If reviews were added through reference checking or manual searching, they were subjected to the same screening process as if they were found in the initial database search. Manuscripts not from peer-reviewed journals, theses or dissertations were excluded.

Section 3: Results

A flowchart of the search process is shown in Figure 2-1. Upon assessing the included articles, certain themes emerged, which form the major sections within the discussion. This narrative review is structured to begin with a broad theme evaluating the effects of RWL followed by a comparison between combat sports and strength sports and finally narrowing to apply the findings specifically to strength athletes.

The first theme discusses the physiological, psychological, and performance impacts of RWL, summarising findings from reviews and attempting to establish a consensus. The second theme explores the similarities and differences in energy systems, the magnitude of RWL, PWI strategies, and potential performance implications between combat sports and strength sports. Lastly, current research findings from combat sports and the limited data on strength sports were extrapolated to provide preliminary best-practice guidance for strength athletes performing RWL.

Figure 2-1 Search and selection process

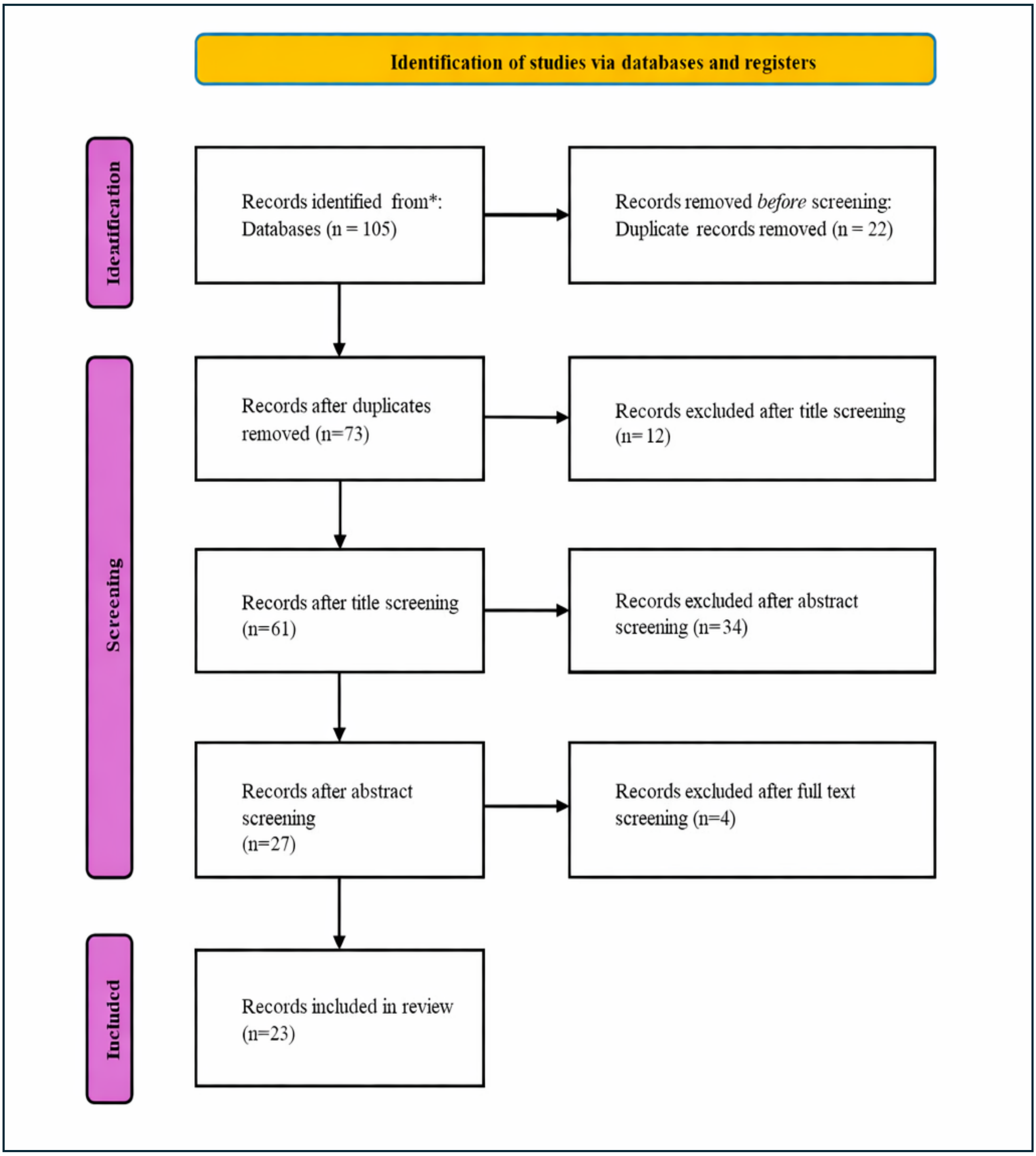


Table 2-1 Summary of evidence from reviews

Study	Types/no of studies	Method of Analysis	Outcome assessed	Measure of assessment	Main Findings
(Brownell et al., 1987)	Not listed	Brief Review	Analysis of metabolic and health effects	Changes in body composition, metabolic rate and physiology.	RWL alters metabolism, adipose activity, health risks, and reproduction.
(Fogelhom 1994)	Not listed	Narrative Review	Effects of RWL on sports performance	The effects of RWL and gradual weight loss on aerobic, anaerobic, muscular strength and endurance performance.	Gradual weight loss may boost VO_{2max}. RWL lowers anaerobic performance and strength, but rehydration (5–24 hrs) restores it.
(Keller et al., 1994)	Not listed	Narrative Review	RWL in adolescent wrestlers	The prevalence, methods, and impact of RWL on performance and physiological factors.	RWL spares strength but reduces aerobic and anaerobic output.
(Artioili et al., 2006)	Not listed	Narrative Review	RWL in grappling sports	Physiological systems and performance in grappling sports.	RWL alters hormones, fat distribution, immunity, cardiovascular health, hydration, renal function, and mood, reducing aerobic and anaerobic performance.
(Loenneke et al., 2011)	No listed	Brief Review	Assessing the rules of making weight in collegiate wrestlers	Validity of minimum weight threshold to protect health of athlete.	Current minimum weight research does not align with RWL estimates in collegiate wrestlers.
(Franchini et al., 2012)	10	Narrative Review	Assessing physiological, psychological and performance effects of RWL in combat sports	BM loss, psychological, physiological, and performance effects of RWL, along with strategies to mitigate performance decline in extreme cases.	RWL is common but harms performance and health through risky methods, impairing physical and cognitive function and increasing death risk.
(Khodaee et al., 2015)	Not listed	Narrative Review	Assessing RWL in sports with weight classes	BM loss and RWL effects on physiology, psychology, performance and health implications.	RWL (<7 days) harms health and performance.
(Aloui et al., 2016)	Not listed	Brief Review	RWL in Judokas during Ramadan	BM loss, methods and performance impact of RWL during Ramadan.	RWL impairs prolonged exercise, mood, perceived exertion, cognition, cardiac output, glycogen stores, and thermoregulation.

(Knox, C., 2017)	Not Listed	Narrative Review	Nutritional recommendations, weight management regulations and practices, and potential disordered eating patterns in high school-age wrestlers	Macronutrient and micronutrient intake. RWL methods and regulations.	Poor RWL and nutrition practices harm performance and raise disordered eating risks.
(Reale et al., 2017)	Not listed	Brief Review	RWL strategies for different combat sports	Methods, prevalence, magnitude of BM loss, weigh-in procedures, weight requirements, and recovery opportunities of RWL.	Athletes use food restriction, dehydration, and intense exercise in RWL, leading to oxidative stress, electrolyte and hormone imbalances, reduced glycogen, altered blood flow, and decreased plasma volume.
(Yang et al., 2018)	9 studies	Narrative Review	Impact of RWL on health and performance	BM loss and methods used for RWL.	Athletes uses dehydration, low-fiber diets to reduce gut content, and glycogen depletion. Risk exists if > 3% of body mass is lost, as this can impair strength, endurance, and heat tolerance. Effective recovery strategies between weigh-in and competition, especially rehydration and carbohydrate replenishment, are crucial to minimizing performance decrements.
(Barley et al., 2019)	Not listed	Narrative Review	Assessing the current research on RWL	Methods, prevalence, and BM loss from RWL, its impacts on performance, and strategies to prevent performance decrements.	RWL methods include energy restriction, fluid reduction, and extreme medical practices. Impact on performance is unclear, but larger weight cuts hinder repeated-effort performance.
(Matthews et al., 2019)	16	Systematic Review	Magnitude of RWL and Rapid Weight Gain (RWG) PWI	Magnitude of RWL and RWG.	RWG magnitude is influenced by sport type, competition structure, and recovery duration. Lack of data quantifying RWL, insufficient evidence linking RWG to RWL, and limited data on females.
(Samadi et al., 2019)	17	Systematic Review	Assessing high-risk behaviours used for RWL	Food intake, anthropometric data, and the negative effects of RWL on physiological and health-related parameters in combat athletes.	RWL is common, especially via fluid loss, with lower-level athletes using dangerous methods like fasting and fluid restriction, harming mental health and performance.

(Lakicevic et al., 2020)	14	Systematic Review	Assessing effects of RWL on Judo athletes	Physiological biomarkers and psychological wellbeing.	RWL increases tension, anger, and fatigue while reducing vigour. The impact of RWL on performance remains unclear.
(Lakicevic et al., 2021)	10	Narrative Review	Assessing effects of RWL on kidney function	Monitoring of serum creatinine, blood urea nitrogen and urine specific gravity.	RWL causes dehydration and acute kidney damage, potentially leading to adverse effects in other body systems.
(Brechney et al., 2022)	17	Meta-analysis	RWL on exercise performance in combat athletes	Maximal strength, maximal power, anaerobic capacity, repeated high intensity effort performance.	RWL does not affect short-duration, high-intensity performance in combat-sport athletes, but some exercise outcomes may decline.
(Lakicevic et al., 2022)	7	Systematic Review	RWL in youth Olympic combat sports	Methods, prevalence, magnitude of BM loss.	RWL is common in youth athletes, with a BM loss magnitude ranging from 1-6.3%.
(Mauricio et al., 2022)	10	Systematic Review with Meta-Analysis	Effects of RWL of 5% BM in less than 7 days in combat athletes	Differences in strength and power measures pre and post RWL.	RWL of ≤5% BM in less than 7 days does not affect strength or power performance in Olympic combat athletes with weight classes.
(Castor-Prage et al., 2023)	13	Systematic Review	Effects of RWL in combat sports	Methods of RWL and magnitude of BM loss. Impact on heart rate variability, executive functions and mood states.	Seven articles reported increased heart rate and negative mood, while two found no significant effects on inhibitory control and reaction time.
(Martinez-Aranda et al., 2023)	16	Systematic Review	RWL strategies and effect of magnitude of BM loss on performance	Perceived fatigue, mood states, strength and power production, as well as changes in hormonal, blood and urine parameters, body composition, and the kinematics of technical performance.	Six studies found no performance impact with a 5% BM loss, while ten studies with 3-6% loss reported negative outcomes.
(Lebron et al., 2024)	Not listed	Narrative Review	Assessing RWL short- and long-term effects on metabolic function	Metabolic rate, substrate utilisation, plasma lactate and metabolic flexibility.	RWL reduces metabolic rate and alters insulin and leptin, potentially preventing more severe disturbances during weight regain, like insulin resistance. The impact on combat athletes is unclear due to limited research, and no definitive conclusions exist.

(Zhong et al., 2024)	26	Systematic Review	Prevalence of RWL, magnitude of BM lost, RWL methods and knowledge in combat athletes	Total weight loss, methods used to lose weight, weight loss history and expert influence.	RWL is common, with athletes starting in their teens, typically 2-3 times a year. They lose <5% body weight in 7–14 days using exercise and dieting, with minimal influence from qualified practitioners.

Section 4: Effects of RWL

Physiological Impacts

The most common physiological effects caused by RWL include, but are not limited to, low energy levels from under-fuelling, dehydration leading to impaired blood plasma and electrolyte balance [49], and, in severe cases, death [50]. These physiological effects are often reported alongside performance impacts [51]. This section will focus only on physiological impacts, while psychological and performance effects will be covered in subsequent sub-sections.

Physiological effects of RWL can be broadly categorised into 1) effects from body water manipulation and 2) effects from non-body water manipulation. The former poses a higher risk to athletes due to the critical role hydration plays in the body. Given that our bodies are approximately 50-70% water [52], theoretically, a significant portion of BM can be lost through fluids. However, hydration is essential for regulating core temperature, maintaining blood pressure, and supporting chemical reactions vital to health and performance [53, 54]. Dehydration risk is further heightened when athletes lose BM primarily through water loss under extreme conditions. Extreme dehydration is often attempted through heat exposure, which can cause numerous adverse effects such as increased heart rate, impaired thermoregulation, cardiovascular strain, and even death [10].

The second category involves BM loss that is not from body water, typically originating from body tissue (fat or muscle), glycogen, and manipulation of gastrointestinal (GI) tract contents [5]. While these methods pose risks, they are generally less severe than dehydration, as there is an upper limit to the amount of BM and GI tract content that can be lost in a short period. Common negative effects in this category include low energy availability, depleted glycogen stores, increased hunger, and perceived energy loss, all of which contribute to higher levels of fatigue and performance decrements [55, 56]. Additionally, although this review focuses on the negative effects of RWL, rather than the long term effects of low energy availability, it is worth noting that chronic weight cycling can impair metabolic, reproductive, and endocrine functions, such as reductions in testosterone and the onset of Relative Energy Deficiency in Sport (RED-S), which can have long-term impacts on athletes [57].

The severity of physiological effects is largely dependent on the total amount of BM lost and the time frame in which it is lost. Combat sports, which allow anywhere from more than 2 hours up to 24 hours of recovery PWI [39, 43], tend to involve larger weight cuts, resulting in greater physiological strain that could take longer to recover from [14]. In contrast, most powerlifters face a 2-hour WIP [15, 58]. Surveys of powerlifters indicate that the average BM loss for a 2-hour WIP is approximately 3-5% [2, 15, 17]. Similar weight loss magnitudes are observed in combat athletes, though typically among those with shorter WIPs [59, 60]. Therefore, arguably, powerlifters who engage in RWL might experience similar physiological effects as combat athletes who lose equivalent weight within comparable timeframes. It is also worth mentioning that some physiological impacts may not necessarily result in noticeable performance declines during competition, as outcomes may depend on PWI refuelling and the specific demands of the competition [51, 61, 62].

Below is a summary of the physiological effects of RWL reported by the reviews:

Table 2-2 Physiological impacts of RWL

Physiological Impacts	Studies	% of weight loss	PWI period
Dehydration: decreased plasma volume, increased heart rate, hydro-electrolytic disturbances, impaired thermoregulation, and muscle glycogen depletion	[43, 54, 63-65]	3%->5%>	12-14 hours
Heat Exposure: increased heart rate, impaired thermoregulation, cardiovascular strain	[11, 56, 66]	5-10%	2-24 hours
Diet manipulation: muscle glycogen depletion, GI sensitivity, increased hunger	[63, 67-69]	2.5%-8%	3-24> hours
Long term impact of repeated or chronic low energy availability: Reduced metabolic, endocrine function and development of RED-S	[57, 70-72]	~5%	N/A

Psychological Impacts

It is essential to understand the physiological impacts of RWL, but it is equally crucial not to overlook the psychological effects that athletes may experience during this process. Recent research indicates validated subjective wellness questionnaires are as, if not more accurate, than objective lab tests in assessing athlete readiness [73]. These perceptual measures allow coaches, researchers, and practitioners to use questionnaires more effectively to monitor athlete status. Indeed, perception is important, as many combat athletes view RWL as an exercise in mental toughness, perceiving their ability to perform it as a psychological advantage over their competitors [74]. However, numerous studies demonstrate that athletes undergoing RWL experience decreases in short-term memory, vigour, concentration, and self-esteem, along with increases in confusion, rage, fatigue, depression, and isolation [75]. These negative psychological states may impact performance through reduced confidence, impaired ability to execute technical tasks, and decreased focus, all of which can lead to poor execution [76]. Magnetic resonance imaging data also indicates that RWL, particularly through dehydration, can reduce cognitive test scores [28] and visuomotor performance and reaction time [77]. Collectively, poor decision-making and impaired motor skills may increase injury occurrence among athletes engaging in RWL, as evidenced by higher injury risk among combat athletes performing RWL [78]. Physiological and biomechanical factors contribute to injury risk; however, psychological and perceptual factors (which can be influenced by RWL) do as well, as pain and injury risk should be considered through a holistic biopsychosocial lens [79].

Rating of perceived exertion (RPE) is a tool to measure the effort exerted during exercise, which is becoming more common in resistance training exercise prescription [80]. Ratings quantify subjective experience during resistance training with descriptions such as "high effort" or "low effort," or based on an athletes perception of how many repetitions can be performed after a set, known as repetitions in reserve (RIR) [81]. RIR-based RPE scores are worthy of note, because they are now common outside of exercise science, used specifically by powerlifters to inform load selection during training and potentially in competition, as demonstrated by their discussion in a recent powerlifting coaching manual [82]. However, since RPE and RIR are subjectively assessed based on the lifter’s perception after a set, RWL may plausibly affect load selection during competition. While research specifically on the effect of RWL on RIR-based RPE scores has not yet been conducted, dehydration can increase Borg-based session and set-to-set RPE scores [83].

Thus, while the influence of RWL on perception may directly impact performance, RWL may also indirectly impact performance. Negative psychological effects of RWL may reduce sleep quality, leading to poorer recovery during the taper week [84, 85]. Recovery may be further compromised by under-fuelling due to energy restriction [72]. Notably, anxiety can cause some individuals to lose their appetite [67], resulting in undereating and, consequently, insufficient fuel for sport. Additionally, chronic repeated use of RWL can lead to potential eating and body image disorders, which may have long-term consequences, especially for, but not exclusive to, younger and female athletes [86].

While the psychological impact of RWL is well-documented, the perceived versus actual impact on performance is influenced by a complex interplay of psychological and physiological factors. Therefore, it is challenging to conclude that a specific psychological effect directly leads to negative performance outcomes. Therefore, coaches should interpret the present findings cautiously, considering them alongside studies directly measuring performance. Below is a summary of the psychological effects reported by the reviews:

Table 2-3 Psychological impacts of RWL

Psychological Impacts	Studies	% of weight loss	PWI period	RWL Method
Impact on mood states: increased tension, confusion, rage, fatigue, depression and isolation	[87-89]	~5-10%	~24 hours	Self-selected
Change in brain structure: impaired memory and visuomotor performance	[10, 45, 90]	2-10%	4-20 hours	Self-selected (reduced fluid intake, sauna, plastic suits, reduced energy intake, fasting 1 day prior, reduced carbohydrate/fat intake)
Complex psychological factors: increased sensation to pain, poorer decision-making during competitions	[39, 75, 91]	2-10%	24-48 hours	Fluid restriction, dehydration, usage of sauna/plastic suits and dieting
Long term impact: negative body image and eating disorders.	[92-96]	N/A	N/A	N/A

Performance Impacts

Research indicates RWL impacts athletes physically and psychologically; however, the most sport-relevant metric is the direct effect on performance. When evaluating the impact of RWL on performance, two distinct categories should be considered: 1) lab-based performance, including metrics such as maximal strength, power, and endurance, and 2) real-world performance measured during competition. While both categories can be useful, it is essential to recognise the limitations of each. Lab-based performance measures are often isolated and measured precisely, allowing for firmer conclusions regarding the isolated, causative effects of RWL. However, it is harder to evaluate RWL's effects on in-competition performance due to the uncontrolled nature of competitive environments. Thus, lab-based performance measures offer strong internal validity, whereas actual competitive outcomes provide greater ecological validity [97], which some may argue is more relevant. When evaluating real-world competition results, some studies indicate that RWL does not negatively impact performance or competitive success [19]. However, these findings may differ by sport, as boxers may not experience negative impacts on performance, whereas Judokas and wrestlers might [20]. These differences could be attributed to the nature of each sport; boxing is more skill and technique-oriented, while Judo and wrestling may rely more heavily on an athlete's BM [19].

A consensus among experts indicates that combat athletes who lose no more than 5% of BM during RWL and are given adequate time to refuel and rehydrate after weigh-ins can mitigate potential negative performance impacts [13, 98]. This consensus aligns with a lab-based study evaluating the effects of a 1.5% bodyweight reduction and subsequent restoration on bench press strength [4]; participants initially demonstrated decreased bench press strength immediately after weight loss, but strength returned after a 2-hour rehydration period.

While there is very little direct data on the impact of RWL on maximal strength performance, the collective evidence indicates that while several factors might influence performance during RWL, these impacts can be minimised with proper weight managment and effective rehydration and refuelling. Although causation between RWL practices and real-world performance cannot be definitively proven at this stage for strength sport, a cautious strategy based on preliminary data is recommended when engaging in RWL to increase the likelihood of competitive success.

Below is a summary of the performance effects reported by the reviews:

Table 2-4 Performance impacts of RWL

Performance Impacts	Studies	% of weight loss	PWI period	RWL Method
Aerobic performance impairments: RWL impacts aerobic capacity to the greatest extent	[43, 54]	5-10%	~3-12 hours	Fasting/food restriction, dehydration/fluid restriction, sauna, increased training intensity, training in thermal clothing, exercise and sometimes prohibited diuretics/laxatives.
Anaerobic performance impairments: occur due to poorer buffering capacity and lack of fuel due to glycogen depletion. This can be mitigated with adequate rehydration and refuelling.	[99-101]	3-5.4%	5-36 hours	Limitation of consumed food and fluids and energy restriction/dieting.
Maximal strength impairments: tend to be impacted the least, especially after rehydration and refuelling.	[46, 102, 103]	2.5-6%	2-18 hours	Dehydration through exercise-heat stress + controlled fluid intake to induce hypohydration and self-selected methods
Competitive success: unstudied in strength sports, variable and currently inconclusive due to different skill requirements, WIP, rehydration post-WIP etc., across different combat sports.	[104-107]	1.9-7%	20-24 hours	Self-selected methods

Section 5: Comparing combat sports to strength sports

Most of the research on RWL is derived from combat sports. Three recent surveys [2, 17, 29] make up a substantial portion of the limited research on RWL in strength sports that shed light on powerlifters' practices, but cannot inform the potential impact of RWL on performance, methods of refuelling and rehydration, or other elements that may differ from combat athletes' practices. Therefore, the following sections seek to clarify differences between combat sports and strength sports, informing preliminary RWL best-practice recommendations for strength athletes.

Energy Systems

Most combat sports rely heavily on the anaerobic-aerobic energy systems, with formats that consist of intermittent rounds lasting 2 minutes, as in boxing and wrestling, or a single longer round [56, 108], as in Judo. Due to the varied nature of combat sports, multiple energy systems are utilised. Short, explosive movements, such as a fast kick or rapid takedown, rely on the creatine phosphate (ATP-PCr) system, which provides energy for short, high-intensity, and maximal strength activities through the rapid breakdown of PCr to regenerate ATP, a process that does not require oxygen. However, the majority of activity in combat sport is fuelled through the anaerobic system, which depends heavily on carbohydrates [109, 110]. As match duration increases, the aerobic system is increasingly engaged. Longer duration Olympic combat sports rely 79%-90% on the oxidative system, while key, point-scoring actions like takedowns and striking rely more on the anaerobic pathway, with the ATP-PCr system contributing between 9%-31%, depending on the combat sport [111].

The energy systems which dominate combat sports contrast with powerlifting and weightlifting, sports that utilise a combination of maximal strength and power [58]. Powerlifting consists of three lifts across three lifting disciplines, while weightlifting consists of three attempts across two disciplines [34]. In these strength sports, the primary energy system used during competition is stored ATP and the ATP-PCr system. While the ATP-PCr system is primarily utilised in competition [112], the glycolytic pathway is engaged during multiple-repetition sets in training

[113]. Research specifically addressing glycogen utilisation during competition is lacking [37]; however, after 20 sets of lower-body exercises performed to failure, in one study by Ivy and colleagues glycogen depletion was ~30% [114]. This finding, however, does not directly replicate powerlifting or weightlifting, as the total work (repetitions) in training differs vastly from competition. In the most representative research, 10 male elite power and weight lifters experienced similar total glycogen depletion to that observed by Ivy and colleagues (30% vs 38%); however, most of this depletion occurred across three subcellular localisations in type 2 fibres, while depletion in type 1 fibres was primarily intermyofibrillar [69]. While these findings indicate powerlifting training can deplete relevant muscle glycogen stores for maximal strength performance to meaningful degrees, future research describing glycogen depletion in competition, and its potential impact on powerlifting competition performance is warranted (e.g., do squat warmups and competition attempts deplete glycogen sufficiently to impact deadlift competition performance?).

Magnitude of Weight Loss

Combat and strength sport athletes lose different magnitudes of BM during RWL due to variations in the WIP between sports – as a longer WIP results in greater losses [115]. Combat athletes have a WIP ranging from three to 24 hours, with most exceeding six hours [39]. Weight loss for combat sport athletes ranges from 4% to 11% [11, 116], with the amount influenced primarily by WIP duration. Studies evaluating WIP that typically exceed two hours, reported an average of 7-8% of BM loss [117, 118], reflecting the established pattern where a longer post-WIP allows for greater weight loss. Amateur combat athletes, who often have a 2–3-hour WIP, lose similar amounts of weight as powerlifters (4-5%). As the IPF, United States Powerlifting Association (USAPL), and the IWF adhere to a two-hour WIP [34, 113], the limited time frame limits the total amount of weight loss athletes attempt, likely due to a shorter rehydration and refuelling period and their desire to preserve performance. As will be discussed in the published Chapter 3 survey [17], powerlifters adhering to these two-hour WIP generally experience BM losses ranging from 2-5%, regardless of age, gender, or weight class, which was further corroborated by Nolan et al [2]. Although longer WIP such as a 24-hour WIP exist in some powerlifting federations, the primary federations admitted to the World

Games (IPF) and that have the highest participation rates use two-hour WIP. Thus, this review focuses on comparisons between combat and strength sports utilising a two-hour WIP.

Besides WIP, there are other factors that influence the magnitude of weight loss, such as sport type, competitive level, age, and biological sex. For instance, Peacock and colleagues demonstrated that male MMA fighters lose more weight than females [119], and Connor and Egan reported professional athletes cut ~1% more weight than amateurs [120]. While BM loss sex differences in strength sports have yet to be explored, as will be discussed in Chapter 3, more competitive lifters tend to cut larger amounts of weight [17], which aligns with findings in combat sports, where higher-level athletes often achieve greater weight loss [77, 121]. Collectively, the data seem to indicate that differences between combat and strength sports are largely influenced by differences in WIP. Indeed, when shorter WIP are used in strength sport, the amount of weight lost closely resemble the amounts found in amateur combat sports that utilise similar length WIP.

Post Weigh-in Refuelling Strategies

Longer WIP are often associated with a greater magnitude of weight loss before competition as it allows the athlete to consume more of food and fluids to refuel prior to competing. The amount of weight an athlete regains after weigh-ins is defined as "weight regain," which is frequently used in studies as a proxy measure for pre-competition RWL [107, 122]. Research indicates weight regain is linked to competitive success in combat sports like judo and MMA, emphasising the importance of refuelling and rehydrating for athletes in these disciplines [20]. Arguably, the primary factor for successful refuelling is selecting the right fuel source. The main substrate responsible for high-intensity intermittent activity is carbohydrate. Studies indicates that higher carbohydrate refeeds enhance performance when the WIP is five hours or longer [123]. A study in collegiate wrestlers found that higher carbohydrate diets improved anaerobic performance more than moderate carbohydrate diets [99] and Judo related performance (5-min combat and Wingate test) was not impacted after a 4-hour high carbohydrate refeed [13]. For athletes undergoing significant RWL with a shorter WIP, replenishing carbohydrates becomes even more critical particularly for combat sport athletes, who commonly experience glycogen depletion during the RWL process [63]. Collectively, adequate carbohydrate consumption can fully replenished glycogen stores within 24 hours [124]; however, shorter WIPs, often less than 24 hours, necessitate prioritising carbohydrate consumption to minimise performance deficits due to incomplete glycogen restoration.

Since the rate of carbohydrate absorption is limited to ~60g per hour from a single-source carbohydrate [125], using a dual-source carbohydrate that includes fructose can increase carbohydrate absorption to ~90g per hour and should be considered for shorter WIPs [126]. Alongside carbohydrate consumption, proper hydration is also crucial. Dehydration significantly impacts performance and physiological processes, since most BM lost during RWL can be attributed to dehydration. Combat athletes typically induce dehydration through a combination of water manipulation and dehydration via heat exposure [11], with the latter posing a slightly higher risk due to heat stress [10, 76]. To minimise dehydration, the amount of fluid consumed should be more than proportional to fluid losses, with current guidelines to consume 150% of what was lost [127]. Despite the importance of PWI rehydration and refuelling, gastric emptying speed can be a rate-limiting factor for replenishing glycogen stores and rehydration [128, 129]. Consuming large amounts of carbohydrate can cause GI discomfort and reduce the efficiency of carbohydrate utilisation, potentially affecting performance [130]. Additionally, the body's ability to absorb water is also influenced by gastric emptying rate [131], as most fluids enter the bloodstream through the small intestine. Exceeding the threshold of fluid absorption, that plateaus around 600-1000ml, could slow gastric emptying and lead to bloating if a large amount of fluid is consumed in one sitting [132].

The optimal of rehydration and refuelling strategy must align with the athlete's capacity to absorb the food and fluids consumed, particularly in sports with a shorter WIP. For strength sports, where WIP typically do not exceed two hours, athletes should avoid consuming excessive fluids and food beyond the body's absorption capacity. However, strength athletes performing maximal strength attempts are less reliant on glycogen during competition compared to combat athletes. If the strength athletes avoid extreme dehydration, current guidelines should be sufficient to ensure proper refuelling and rehydration.

Performance Implications

The current research in combat athletes indicates that the larger the magnitude of RWL, the greater the chance of performance impairment [66, 75], which is not clearly seen in powerlifters. As will be discussed in Chapter 3, more competitive lifters tend to cut a greater percentage of BM, and these lifters either have a higher coefficient score or win more medals in international competition [17]. However, a factor that may contribute to the success of these lifters is the number of competitions done per year; lifters who competed in ~3 competitions were favoured to win more medals. Perhaps, more competition experience permits lifters more frequent practice of RWL, potentially minimising negative impacts that would have otherwise occurred. Further, the amount of weight lost by these more competitive lifters is similar to that of amateur combat athletes (~4-5%), an amount that did not impair performance in Judokas ([13]).

The element of RWL most likely to impact performance is dehydration, which is a common issue across nearly all forms of exercise and sports, regardless as to whether or not RWL is implemented [133-135]. While the specific impact of dehydration during RWL on combat sports performance and competitive success cannot be isolated due to the nature of the studies' design, non-combat sport research indicates dehydration of 2-4% can increase blood lactate during activity [136]. Further, Schofstall and colleagues reported that dehydration equal to a 1.5% BM loss can reduce maximal strength in the bench press [4]. However, most of these negative impacts can be mitigated through PWI refuelling and rehydration provided that the magnitude of BM loss is not too large and the WIP is sufficient. In the case of Schofstall and colleagues, the decrease in bench press performance caused by the 1.5% dehydration was completely restored 2 hours after rehydration [4]. Judelson and colleagues also reported that dehydration can reduce maximal strength ~2%, but did not account for any rehydration strategies PWI [46]. Therefore, RWL through dehydration increases the chance of a decrease in maximal strength when adequate rehydration is not present.

Other aspects such as heat, different types of performance, and the magnitude and timing of dehydration and rehydration are also relevant when discussing the effects of dehydration on performance. Barley and colleagues reported a 5% BM loss via dehydration induced through 3 hours of cycling in 40 degree Celsius heat reduced repeated effort performance even after 24-hours [14]. After hydration levels returned to baseline, performance was still impaired, likely caused by cardiovascular strain due to reduced blood volume, a known side effect of dehydration. Thus, while performance decrements from mild dehydration (BM loss of ~1-1.5%) can likely be reversed, greater levels of dehydration may still impair performance even after 24 hours. There are also anecdotal reports of lifters experiencing muscular cramps during competition. While cramps used to be attributed to one or a combination factor such as dehydration, lack of electrolytes, an energy deficit and other factors [137], current research indicates the specific aetiology of muscle cramps is not fully understood, but may be related to central nervous system regulation [138]. Therefore, it is currently premature to attribute RWL as a sole cause for muscle cramps during competition, especially when there are also reported incidences of lifters who do not engage in RWL experiencing such cramps.

Finally, there are also studies indicating performance may be negatively impacted in combat athletes due to severe energy restriction which can lead to fatigue [139, 140], depletion of muscle glycogen stores or both [63, 141]. However, research demonstrates a low carbohydrate diet (<50g/day) combined with a minor energy deficit (< 10%) can induce ~2% BM losses without compromising performance [142]. While no performance loss was observed in this specific study, the impact on performance if BM losses were greater is unknown, especially considering that modest total glycogen depletion can be concentrated in specific subcellar sites which might be critical to strength performance [69].

Section 6: Best practice for the strength athlete

Currently, the research available on strength athletes is limited compared to that on combat athletes. However, by carefully evaluating the similarities between these two sports, we can begin to formulate evidence-based practices that may benefit strength athletes. Arguably, the most critical factor to consider is the magnitude of weight loss. Existing work by Nolan and colleagues and in the present Chapter 3 survey [2, 17] aligns with the combat sports literature in recommending that, for weigh-ins occurring less than three hours before competition, no more than 5% of BM should be lost. This limit ensures that the negative impacts of weight loss—whether physical (e.g., dehydration, heat stress, hunger) or psychological (e.g., negative mood states)—can be sufficiently mitigated.

A shorter period for the athlete to rehydrate and replenish after the weigh-in is another crucial factor. Current combat sports research suggests that weight regain and competitive success depend on the nature of the sport (e.g., striking versus grappling) [19, 20]. However, adequate rehydration and replenishment can mitigate performance decrements [13] if RWL is not excessive. For strength athletes, proper rehydration and replenishment strategies should be tailored to the RWL method used and the magnitude of weight loss. A greater magnitude of weight loss, more invasive methods (e.g., dehydration, heat exposure), or a combination of these factors would necessitate a stronger emphasis on refuelling and rehydration. Due to the shorter time available PWI, excessive food consumption may pose challenges. Combat athletes, who typically have 24 hours to replenish, often prioritise high-carbohydrate foods to restore muscle glycogen and fuel high-intensity intermittent activity. Given sufficient time for digestion, glycogen stores can be replenished within this period [124].

In contrast, strength athletes competing within a two-hour window, and primarily utilising the ATP-PCr system do not require substantial carbohydrate intake, as maximal strength efforts are not as dependent on glycogen. Instead, carbohydrate consumption through sports drinks should suffice to meet energy demands while simultaneously ensuring adequate hydration, a factor more likely to negatively impact maximal strength if neglected [46].

Lastly, hunger, as a subjective perception, varies among athletes and should not be underestimated, as it may impact performance [143]. While the metabolic and physiological demands of refuelling can be met without excessive carbohydrate consumption, PWI nutrition should be managed to alleviate hunger without causing bloating during competition. The optimal approach will depend on the individual athlete's comfort level with food consumption in this context.

Section 7: Future considerations

The current literature on RWL for strength athletes is limited. Given the widespread use of RWL, more research is needed to develop guidelines that allow strength athletes to implement RWL safely. Among other gaps, two critical gaps in the current knowledge are the lack of normative ranges for weight loss achieved through different RWL methods and the optimal timing of heat exposure to induce dehydration without negatively affecting strength performance.

Most of the existing literature on combat sports is retrospective, with RWL methods being self-reported by athletes. While this provides valuable insights into real-world practices, it does not establish normative BM loss ranges for RWL achieved through specific methods. This information is crucial because, for a 2-hour WIP, not all strength athletes will opt for significant BM loss. Understanding which RWL methods correspond to specific amounts of weight loss can help athletes avoid unnecessary losses that could impair performance. For those requiring greater weight loss, identifying these normative ranges may also assist in setting realistic expectations and improving off-season body weight management.

As will be discussed, surveys of elite powerlifters suggest that more competitive lifters often achieve greater magnitudes of RWL. While research indicates that a 2-3.5% RWL is achievable without heat-induced dehydration, some elite lifters report even greater losses, which likely require dehydration, potentially through heat exposure. However, there is insufficient research on best practices for these RWL methods. Since heat-induced dehydration is generally considered the most aggressive and potentially harmful RWL approach if not executed properly, further research is important and much needed. Cases of RWL-related fatalities in combat athletes following prolonged heat exposure underscore the risks associated with heat-induced RWL dehydration methods. Arguably, these concerns are particularly relevant for elite strength athletes, who frequently aim for RWL exceeding 3% in a short time window.

This review leveraged the best available data on RWL practices in combat athletes to inform recommendations for strength athletes, identifying key differences, gaps, and limitations. These insights aim to guide future research in developing safe and effective RWL practices for this demographic.

Chapter 3 Prevalence, magnitude and methods of RWL in world class powerlifters.

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Prelude

The literature review (Chapter 2) demonstrated that there exists a gap between the practice of RWL for combat athletes and WRSA. Specifically, the magnitude of BM lost through RWL can vary greatly due to the often-shorter PWI period. Thus, the specific method(s) of RWL selected should depend on the magnitude of BM an athlete must lose. Further, the literature on the effect of RWL on combat sport performance varies due to differences in the specific skill-based nature of the combat sport in question and in different levels of competitiveness. Therefore, Chapter 3 was designed to investigate RWL prevalence, magnitude of BM losses and methods of RWL used among world class powerlifters, based on these being known factors which influence combat sport performance. As a notable methodological advantage, this survey was done in person at the 2018 IPF World Championships.

Section 1: Introduction

Powerlifting is a strength sport consisting of three competitive movements: the squat, the bench press and the deadlift. The overall winner is determined by the highest total load lifted in all three lifts in the lifters' respective weight classes. In the IPF there are a total of eight weight classes for both male and female lifters, respectively. Due to the segregation of weight classes and the relationship between BM and the ability to carry a larger amount of muscle mass and strength [40], many powerlifters choose to compete in a weight class lower than their habitual weight to gain a competitive advantage (16). This results in the use of various RWL strategies to "make weight" prior to a powerlifting competition.

There are numerous studies which show that undergoing RWL can result in impaired exercise performance [144], increased injury risk [145], negative psychological effects [146] and in extreme cases, the risk of death [147]. By losing a large amount of BM in a short period, athletes expose themselves to physiological side effects such as reduced plasma volume [66] and impaired thermoregulatory processes which can affect exercise performance [148], electrolyte imbalance which can affect muscle contractility [131], and higher markers of muscle damage [149].

Athletes' psychological state can also be affected during RWL [75]. Symptoms of depression, a reduction in concentration, and an increase in confusion are commonly present in athletes undergoing RWL [88]. Dehydration specifically can reduce blood flow to the telencephalon [150], a major part of the brain which could cause a reduction in metacognitive abilities. Moreover, dehydration can lead to an increase in RPE [83]. Given that RPE can be used to prescribe load to [151] inform resistance training for powerlifting [152], an increased RPE could potentially have a negative influence on attempt selection during competition, which is a predictor of competitive success in powerlifting [153].

In addition, methods of dehydration used during RWL can pose significant negative impacts on both performance and health. One study demonstrated that dehydration causing a 1.5% decrease in BM led to a 5% reduction in bench press 1-repetition maximum (1RM) [4], while another study showed that dehydration led to a consistent decrease in total work completed (measured by volume load) during resistance training [46]. In addition, injury risk increases in combat athletes who lose more than 5% of their BM before competition [145]. Lastly, in extreme cases, death can occur from RWL, as seen when three Olympic wrestlers passed away due to severe dehydration, resulting in reduced potassium levels which altered the activity of the sodium-potassium pump, causing cardiac arrest [147].

While there is a robust amount of research demonstrating that RWL has negative impacts on health and performance, most of this research is done in wrestling, jujitsu, karate and other combat sports. To our knowledge, there is only one study on RWL among powerlifters by Nolan and colleagues [2], but this study was done across the powerlifting population, at multiple competitive levels. Thus, our study aimed to complement the existing research by specifically surveying world class powerlifters to examine the prevalence of weight cutting practices at the elite level, and to assess if there were any associations between weight cutting practices, competitive success, and mood state and perceived stress.

Section 2: Methods

Experimental Approach to the Problem

Powerlifters that competed at the 2018 IPF classic World Championships were invited to complete a survey after they had finished competing. The survey was based on a previous validated questionnaire [116] but modified to ensure relevance for powerlifting. From the data collected, a cross-sectional approach was used to assess the relationship between competitive success (winning a medal), prevalence of weight cutting, methods of weight cutting, participant characteristics (e.g. age, experience, gender, Wilks Score, etc.), and perceived psychological stressors during weight cutting and competition among world class powerlifters.

Subjects

Powerlifters (>18 years of age) competing at the IPF World Classic Championship 2018 in Calgary, Canada participated in this survey of weight cutting strategies. Participants were voluntary and approached in person by the researcher post competition. The only exclusion criteria were women in the 84kg+ and men in the 120kg + weight class, as these weight classes do not require the athletes to perform any form of weight cutting to make weight. A sample of 64 (42 males and 22 females) athletes were surveyed during the length of the competition. For analysis, the participants were separated into two groups based on competitiveness; those who won a medal versus those that did not. All athletes competed under the “classic category” standard stipulated by the IPF. This category permits the athlete to wear knee sleeves, wrist wraps, lifting belt and a non-assistive powerlifting singlet. All athletes also needed to comply to the IPF standard of competing drug and banned substance free.

Procedures

The RWL questionnaire was designed and validated by Artioli and colleagues and was meant for the assessment of RWL practices in Judo athletes [116]. Therefore, after consulting with powerlifting coaches and pilot testing with powerlifters, modifications of certain terms such as "competition" to "powerlifting meets" and other minor changes were made to make it suitable for use with powerlifters. Briefly, the RWL questionnaire asked the participant to report the prevalence of various weight cutting strategies as "never," "almost never," "sometimes," "always," or "stopped using," as well as the prevalence of five perceived psychological states using the same qualitative descriptors.

Lifters were approached for recruitment after they had competed, and volunteers were provided a hard copy of the questionnaire. Further, the principal investigator verbally discussed the questions with each participant to remove any ambiguity the lifter might potentially have about the questions. The athletes' competitive performances were separated and analysed for variables such as age, weight class, final RWL score, meets competed, number of cuts performed, weight lost for this competition (% of BM), most weight lost (% of BM), how long prior to competition cuts began, weight regain post competition, perceived performance decrement during training and Wilks score (a measure for strength relative to body weight and a higher wilks score indicates a stronger and higher calibre lifter). The data collected was then entered into a Google form after the end of the competition. The survey was done from the 11th to the 17th of June 2018. Ethical approval for this research was obtained from the University ethics committee (approval number 18/161) and all study volunteers provided informed consent after having the study procedures explained in detail prior to participation.

Statistical Analyses

The RWL questionnaire was scored as per Artioli and colleagues [116] to produce a final RWL score for each athlete. Frequency analyses were performed for methods of RWL and psychological effects experienced during RWL. Statistical analyses were completed using JASP (version 0.13.1, University of Amsterdam, Amsterdam). Descriptive statistics (i.e., mean, standard deviation [SD] and frequency analysis) were used to report athlete characteristics based on their responses to the questionnaire which provided ordinal data. An independent T-test was used to compare parameters across the independent variable of athlete calibre (medal vs no medal). A chi-square test was performed to compare associations between categorical variables (i.e. medal count, perceived decrement in training performance and "did you cut for this meet?"). Statistical significance was set at $p \leq 0.05$.

Section 3: Results

Out of a total of 64 respondents (42 males and 22 females), 53 engaged in weight cutting in preparation for this competition. Athletes were categorised based on competitive performance (won a medal versus no medal). Characteristics of the combined sample, medallists, and non-medallists are shown in

Table 3-1. 90% of medal winners engaged in weight cutting for this competition, while only 10% did not who won a medal. Among non-medal winners, 70% engaged in weight cutting while 30% did not. The medallists lost an average of 4.1 ± 4.6 % of BM while non-medallists lost 2.7 ± 3.1% of BM, respectively. The most weight medallists lost throughout their competitive career was 5.7 ± 3.4% of total BM, while non-medallists lost 4.7 ± 2.3% of BM. Medallists reported a higher RWL score (32.8 ± 11.3) than non-medallists (28.5 ± 11.1), but this difference was not significant ($p < 0.08$). 12 respondents reported that they perceived a decrement in their training performance, 11 of whom engaged in weight cutting. However, a reported perceived decrement in training performance did not exhibit a significant relationship with winning or medal or not X^2 (1, N = 64) =0.767, p = 0.381.

Winning a medal was only significantly associated with the number of meets participated in that year ($p = 0.025$) and Wilks score ($p < 0.001$), which is a score that represents relative strength for comparisons across weight classes [154]. Finally, significantly more athletes who won medals, also cut weight X^2 (1, N = 64) =5.063, p = 0.024.

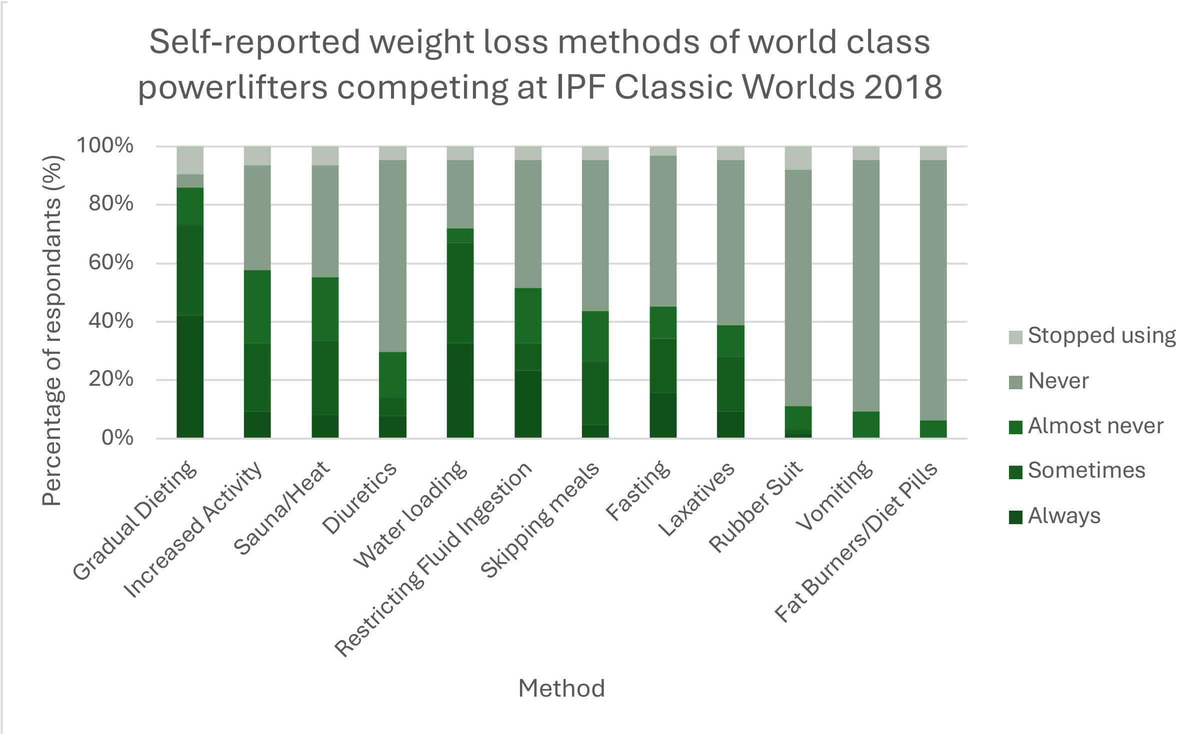
Table 3-1 Self-reported characteristics of world class powerlifters competing at IPF Classic Worlds 2018

	Total participants	Medal	No Medal
Age	26.2±6.5	25.8±6.7.0	25.4±4.6
Body mass	72.2±16.1	76.6±20.1	77±14.9
RWL Score	31.5±10.7	32.8±11.3	28.5±11.1
What age did you start powerlifting?	21.3±5.2	20.7±5.4	21.4±4.2
How many meets did you compete this year?	2.1±0.9	2.7±1.3**	2±0.9
How many meets in the past year did you cut for?	2.3±1.4	2.4±1.1	2±1.6
How much weight did you lose for this meet (% of bodyweight)?	2.9±4.3	4.1±4.6	2.7±3.1
What was the biggest weight cut you done in your competitive career? (% of bodyweight)	5.4±3.2	5.7±3.4	4.7±2.3
Athlete Calibre (measured by Wilks)	456±39.2	481±42.5**	435.4±30.9
How long before the meet did you start cutting weight (days)?	32±33.2	27.4±29.4	29±31.3
How much weight do you regain in the week after competition?	2.6±2.2	2.7±2.3	2.2±2.03

Significant differences marked as ** $p < .05$

As shown in Figure 3-1, the most commonly used method to make weight for competition was fluid restriction following fluid ingestion and gradual dieting. 32.8% and 42.1% reported they “always” used these respective methods. The least common method to make weight was using fat burners/diet pills and vomiting with 89.1% and 85.9% reporting “never.” Surprisingly, “stopped using” results were quite similar across all methods ranging from 3.1%-7.8%.

Figure 3-1 Self-reported rapid weight loss methods of world class powerlifters competing at IPF Classic Worlds



Regarding the effects of weight cutting (Table 3-2), 15.6% of athletes reported they “always” experienced fatigue and anxiety, making them the most common negative psychological states experienced. However, more athletes reported “sometimes” across fatigue, anger and anxiety with 45.3%, 26.6% and 35.9% respectively reporting these outcomes. The least experienced negative emotional state was depression and isolation, in which the athletes reported only 4.7% and 3.1% for “always.”

Table 3-2 Self-reported psychological state of world class powerlifters competing at IPF Classic Worlds 2018

Psychological State	Always (%)	Sometimes (%)	Almost never (%)	Never (%)
Fatigue	15.6	45.3	21.9	17.2
Anger	3.2	26.6	25.0	45.3
Anxiety	14.1	35.9	14.1	35.9
Isolation	4.7	12.5	25.0	57.8
Depression	3.1	7.8	26.6	62.5

Section 4: Discussion

To the knowledge of the authors, this is the first study conducted in world class powerlifters that assessed the prevalence, magnitude and methods of weight cutting in preparation for competition. We conducted this study in elite athletes in person during the duration of the 2018 IPF World Classic Championships. This is an important factor for two reasons, the first being our survey was collected shortly after competition which minimises recall bias [155] and the second being that this was done in world class athletes, allowing us to observe the practices of elite athletes and to identify any potential differences with those who are not as competitive [103]. We found that amongst world class powerlifters, the prevalence of weight cutting is high, as 83% of the athletes made weight using a combination of RWL and gradual dieting. The average weight loss using these methods was ~2.9% of BM. While gradual dieting would not fall under RWL, usage of gradual dieting had a high prevalence as well, which is why we included the data in our final analysis. However, despite obtaining both total amount of weight loss and the methods used to achieve this weight loss, details such as macronutrient distribution and calorie consumption were not recorded. This is because the survey was based on a previous survey and calorie and macronutrient intake was not a part of the survey. Secondly, recalling specific calorie intake can be highly inaccurate if no prior tracking was done, hence the researchers decided not to include it as part of the survey. A study done by Nolan that surveyed powerlifters of a lower competitive level on average with the same questionnaire showed that both the prevalence of weight cutting and magnitude of weight loss were similar with the findings of our study, at 85.8% of respondents and 3.0% of BM, respectively [2]. While both our survey and Nolan's were not validated specifically for powerlifting, similar findings between both surveys indicates potential utility and could warrant a validation study in the future.

We further segregated the athletes according to competitive success (medallists versus non-medallists) to identify any potential differences in weight loss practices. We found that athletes that performed some form of weight cut leading into this competition tend to win medals more often compared to those that did not. There was also a difference in magnitude of BM loss between the athletes who won a medal and those who did not win a medal (4.1% vs 2.7%), but this difference did not reach statistical significance ($p = 0.13$). Future research with a larger sample size is needed to determine if this lack of significance could be due to our relatively small sample size. Unsurprisingly, medallists had a higher overall Wilks score than non-medallists, but the medallists also competed in more meets throughout the year, indicating that athlete experience with weight cutting might play a potential role in weight cutting success. This could be attributed to elite athletes being predisposed to use RWL strategies that are more severe in nature in order the gain a competitive edge over their opponents, hence prior experience may allow more successful execution of a severe weight cut [103]. Another interesting finding was that in the study by Nolan and colleagues [2], the average Wilks score for athletes categorised under "High Wilks" was 429, whereas in our study those that did not win a medal averaged 435 Wilks, indicating a difference in the athlete calibre surveyed between our and the study by Nolan and colleagues. Further, the usual amount of BM lost prior to competition by the high Wilks group in Nolan's study and the non-medallists in our study were both 2.7%. These comparisons may support the notion that the more elite the athlete is, the greater the tendency for the athlete to cut more weight to potentially gain a competitive edge over opponents, which is similar to findings seen in the literature on combat sport athletes [90].

Although the athletes that won medals lost more weight compared to those that did not, the weight loss compared to other weight class sports was lower. In combat sports such as Judo and MMA, the range of average weight loss is between 6 – 11% of BM [156] whereas in our study it was only an average of 2.9%. However, severity of the cut cannot be measured solely by the amount of weight lost and thus, analysing the total RWL score might provide a more complete picture. The medallists in our study reported a higher average RWL score compared to non-medallists (32.8 vs 28.5) and the average score across all lifters was higher compared to the scores reported by Nolan and colleagues (31.5 vs 25.1). Indeed, the average RWL score from our study is more like some cohorts of elite and experienced taekwondo athletes [156] that reported scores of 31.7. These similarities might imply that higher level athletes not only cut more weight but utilise more severe methods to do so.

The discrepancy in the magnitude of weight loss between powerlifters and combat sport athletes despite a similar severity in RWL score could simply be due to the shorter time available to refuel and rehydrate following weigh-ins. In combat sports and MMA competitions, rules typically allow 24-36 hours between weigh-ins and competition, compared to just 2 hours in powerlifting. Previous research in combat sport athletes also indicates that the more time available between weigh-ins and competition, the greater the tendency for an athlete to perform a cut of larger magnitude [157].

Rapid weight gain (RWG), which is the total amount of weight gained during an athlete in the PWI, is a commonly used surrogate marker of total weight lost. Drawing upon data from Australian Olympic combat sport athletes, one cohort reported RWG of roughly 4.3% [156] compared to 2.6% reported in our current survey. This suggests that combat athletes more aggressively employ RWL prior to competition compared to powerlifters. Further, in combat sports the magnitude of RWG immediately after weigh-ins prior to competing can be a predictor of competitive success [20], but this finding is sport-specific as it was not observed in boxing [44]. This might indicate that combat sports involving grappling, when additional BM might provide an advantage, could benefit more from RWG than striking sports. However, the effect of acutely higher BM (due to rehydration) on powerlifting performance is unknown, and thus, the influence of RWG on powerlifting performance is not well elucidated and warrants more research.

From our study, elite athletes commonly used water loading and cutting (32.8%) and gradual dieting (42.2%) to make weight, while the usage of sweating-based RWL methods such as sauna/heat (7.8%) and rubber suits (1.6%) were not as common in terms of the percentage reported as "always" used. This confirms findings from Nolan and colleagues showing that prevalence between powerlifters and combat sport athletes were similar when it came to the usage of water manipulation and gradual dieting, but there was a stark difference in sweating-based RWL methods. Fasting was only somewhat common, as 15.6% reported “always” and 18.7% reported “sometimes”; this method might be less popular among powerlifters as its utility could be influenced by the shorter time available to recover PWI. Since the powerlifters we surveyed had only < 2 hours permitted between weigh-ins and competition, there might be insufficient time to rehydrate and refuel, especially when the amount of weight loss is large. While there are currently no studies investigating rehydration in powerlifters, a study that measured an 18-hour rehydration period in wrestlers losing 3.5% of BM showed that it was insufficient for full recovery [76]. While a study done in competitive weightlifters showed that a 2-hour period of rehydration was sufficient to prevent a decrement in performance after 4.3% of BM loss [25]. The differences between these studies could be due to different performance demands, or it could potentially be caused by the study’s use of an ad-libitum fashion PWI rehydration and refuelling period, without accounting for the exact amount of food and fluids consumed. In an uncontrolled environment, there is a potential for athletes to under eat or rehydrate due to suppression of thirst and appetite post RWL [158], which might influence the degree of recovery across different athletes. Hence, more research into the areas of rehydration and refuelling PWI for strength athletes is needed to establish evidence-based recommendations to minimise performance decrements.

The psychological effects of RWL are well documented in the combat sports literature with similar findings observed in the present study. Our participants reported increased levels of anger, fatigue, and anxiety, which were similar to increased levels of confusion, rage, fatigue, depression, and isolation found in combat athletes [75]. Investigators reporting powerlifters’ RPE-based load selection accuracy noted that more research is needed to determine if fatigue influences load selection accuracy [151]. Thus, the finding that RWL increases perceived fatigue makes the decision to perform RWL for powerlifting an important consideration. Athletes should assess whether an increase in negative emotions and perceived fatigue, which could plausibly cloud one’s judgement when selecting appropriate attempts, is worth engaging in RWL.

Lastly, there is a limitation that relates to sampling. Due to convenience-based in-person data collection, male competitors were nearly twice as represented as female competitors. Although this may partially reflect elite participation patterns, it may limit the generalisability of these findings to female powerlifters, particularly given evidence of sex-specific differences in weight management practices in other weight-class sports.

Section 5: Practical Applications

Elite powerlifters competing at IPF Worlds report losing on average ~3% of BM prior to competition. However, lifters that won a medal reduced BM by an average of 4.1%. There was an association between the number of competitions per year and increased success in winning a medal. These findings might indicate that the more practice cutting weight an athlete has, the less likely it will hinder their performance. Water loading and cutting seems to be the most commonly used method in conjunction with some form of gradual dieting; considering their frequent use at the elite level, this might indicate these methods have a lower chance of harming performance. When selecting a RWL method, one should consider the potential benefit of experience. Specifically, the method most familiar to the athlete could be an important factor in deciding which method to use, as there is not enough information on the advantages or disadvantages of any specific method. Finally, an athlete might experience negative psychological effects from RWL which may need to be managed during the RWL process and during competition in order to prevent athlete burn out or errors in attempt selection.

Chapter 4 Using the Short Recovery and Stress Scale to Evaluate Changes in Wellbeing and Performance in World Class Powerlifters

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Prelude

Chapter 3 demonstrated that over 80% of world class powerlifters performed RWL when competing at the World Championships. The average weight loss was approximately 3% and most commonly, lifters incorporated gradual dieting and fluid restriction after fluid loading. In addition, 91% of powerlifters experienced negative psychological impacts, with fatigue and anxiety being most common. Lastly, 11 out of 12 powerlifters who experienced a drop in training performance performed RWL. Thus, to build on these findings, the purpose of Chapter 4 was to examine the relationship of RWL and changes in subjective wellness across the seven days leading into weigh-ins. Further, the aim was to explore if changes had any relationship with competitive performance. These data can help coaches and athletes improve their RWL methods to mitigate any negative impacts on high level competition. To improve accuracy, like Chapter 3, this survey was done in person in the 2019 and 2022 IPF World Championships.

Section 1: Introduction

RWL is well-studied in combat sport, and is typically characterised by a BM reduction of 2% to 5% (although more occurs in some sports, as to be discussed) in a short period, often within five to seven days of competition [1]. RWL is also a common practice of powerlifters regardless of lifting experience [15] and more than 80% of powerlifters utilise some form of RWL strategy to achieve the weight required for their weight class [2, 15, 17]. The method of RWL varies from lifter to lifter, and this variance in approach can lead to different amounts of weight lost and may negatively influence performance due to dehydration, or fatigue from a reduced energy intake [4, 15]. As demonstrated primarily from research in combat sports [11, 12], the greater the magnitude of weight lost through

RWL, the greater the potential for a negative impact on athlete performance, psychology, and physiology. Further, negative psychological impacts from RWL have been recorded in powerlifters [17].

While both combat sport athletes and powerlifters engage in RWL, a notable difference between the two sports is the magnitude of weight loss. Combat sport athletes tend to lose greater relative amounts of weight compared to powerlifters [159], partly because powerlifters in the IPF; the largest powerlifting sports body, have only two hours PWI to refuel and rehydrate [34] compared to combat sport athletes who have three to 30 hours depending on their specific sport [44]. Notably, the more time available to an athlete to rehydrate and refuel PWI, the more aggressive their approach to RWL will be [160]. Powerlifters on average lose ~2-6% of BM [15] from RWL whereas combat athletes often lose up to 5-8% [11]. This distinction is important because the negative impact of RWL on physical and mental performance is exacerbated with greater losses of BM, given the same amount of time to refuel and rehydrate [15, 107]. Moreover, a longer PWI refuelling period may help mitigate the negative effects of RWL on an athlete's physical and mental performance [13].

There are several RWL strategies that powerlifters utilise. The first involves reducing body weight by manipulating residual food weight in the gut, achieved by omitting fibre and consuming foods that are more energy dense [17]. The second strategy is dehydration through fluid manipulation, commonly done by increasing water consumption followed by a steep reduction prior to competition, known as water loading, which increases acute body water reduction to a greater degree compared to fluid reduction alone [127]. Lastly, dehydration can also be induced through heat exposure, leading to sweating. These methods are like those used by combat athletes, but the magnitude of body weight loss tends to differ. Therefore, current research on the negative impacts of RWL in combat sport athletes cannot be directly extrapolated to IPF powerlifters with a shorter PWI window.

Powerlifting performance can be influenced by BM manipulation [153] and attempt selection [58]; i.e., the load selection strategy athletes choose for each lift attempt. Additionally, one paper suggested that the opening squat may be the most important lift of the competition [161], as its success changes the probability of a successful competition overall. Since the first attempt squat is the performance most proximal to the weight cut, a greater magnitude of body weight induced through RWL makes it harder for the lifter to rehydrate and refuel within the two hours after the weigh-ins, which may impact first-squat performance.

Given the potential relationship between RWL and powerlifting success, more research is warranted to investigate how RWL strategies impact an athlete's readiness and performance. These factors and the gaps in the existing research led us to conduct in-person surveys to determine the relationship of weight change with subjective well-being and readiness over seven days prior to competition, in world class powerlifters competing at two IPF World Championships. The outcomes of this survey may be important, as psychological pressure can negatively impact performance [45]. Further, a more positive mental state—achieved by reducing competitive anxiety and improving mood through better emotional control and the ability to maintain confidence—has led to greater athletic success in other weight class-based athletes [25, 45]. To explore the potential relationship between perceived stress, recovery, and performance in powerlifters, we utilised the SRSS scale, an easy to use, previously validated scale [162]. We hypothesised that there may be a relationship between SRSS category scores and certain descriptive factors, such as body weight loss, time, and the competitive level of the powerlifter.

Section 2: Methods

Data collection for this study was completed at the 2019 IPF World Championship in Helsingborg, Sweden, and the 2022 IPF World Championship in Sun City, South Africa. A convenience sample of potential participants were recruited via social media and/or email and the only inclusion criteria were that they were a competitor at the World Championship and had the availability and willingness to participate. The aim of the current study was twofold. First, to explore subjective well-being, readiness, and weight change over seven days in IPF powerlifters competing at the 2019 and 2022 World Championships, using the SRSS. The SRSS was used to determine how predictors such as competitive calibre (reflected in a strength relative to BM coefficient score, scored in the IPF as GLP), sex, and magnitude of RWL affect SRSS scores. In addition, we tested if competition performance was affected by the magnitude of RWL. We then evaluated the interaction of the readiness score of the participants across multiple categories, including day, body weight, competitive division, biological sex, and GLP.

Participants were informed they would need to complete the SRSS, an eight-question questionnaire using a seven-point Likert scale at three different time points: the day before they began any form of acute RWL (day 7, 6-7 days before the meet), two days prior to the meet (day 2), and immediately after weigh-ins (day 0). The SRSS was chosen for its ease of use and its validity when compared with biomarkers such as cortisol and creatine kinase in weightlifters, a strength-power sport that also utilises a two-hour WIP [162]. Participants were familiarised with the SRSS questionnaire during the first meeting (day 7) in detail, giving each participant instructions on how to answer each item. The SRSS consists of eight items that measure physical, mental, emotional, and overall aspects of both recovery and stress [162]. The four items measuring recovery include Physical Performance Capability (PPC), Mental Performance Capability (MPC), Emotional Balance (EB), and Overall Recovery (OVR). The subsequent four items measuring stress include Muscular Stress (MS), Lack of Activation (LOA), Negative Emotional State (NES), and Overall Stress (OS). Each item is described with a list of adjectives, and participants rank them on a scale from 0 to 6, with 0 being “does not apply at all” and 6 being “fully applies.” The eight subscales of the SRSS are structured such that better perceived recovery is characterised by higher responses, and improved stress by lower responses, on the 0 to 6 scale. In addition to completing the questionnaire, participants' body weight was recorded at three time points on their personal scale that was calibrated to the scales of the competition (morning body weight on day 7 and day 2, and official weigh-in weight on day 0). Participants' overall competition placements were recorded. Informed consent was obtained prior to participation. This study was approved by the University’s ethics committee, ethics application number 18/161.

The SRSS questionnaire can be found in Appendix C Questionnaire from Chapter 4.

Statistical Analysis

These statistical analyses are exploratory and aim to identify patterns and associations between variables of interest (i.e., how proximity to competition, sex, competitive calibre, and magnitude of acute weight loss, and the interaction of these variables, affect recovery and stress ratings) in our dataset [163]. We employ an estimation based approach [164] to report model estimates (and their uncertainty) that are of interest when identifying patterns or associations in the dataset. P-values are reported for completeness but are not interpreted in their traditional manner due to the exploratory nature of our analysis.

All statistical analysis was performed in R statistical language (version 4.4.1; R Core Team 2021). The dataset and analysis code are available on the Open Science Framework (URL: https://osf.io/cf954/). To explore the effect of weight change on GLP at competition, a linear model with fixed effects (with interaction terms) for day 7 to 2 weight change, day 2 to 0 weight change, and sex was performed using the *lme4* package [165]. Linear model assumptions were checked using the *performance* [166] package.

Given the ordinal data structure obtained from the SRSS, cumulative link mixed models (CLMM) were performed in R using the *ordinal* package [167]. Maximum likelihood estimation within the logit model was used. The number of adaptive Hauss-Hermite quadrature points was set at five for all CLMMs. A full model was constructed on grounds of data availability and potential theoretical interest. The full model included fixed effects with interaction for day (three levels: day 7, day 2, and day 0), weight change from day 7 to 2 (continuous), weight change from day 2 to 0 (continuous), competitive division (2 levels: male or female), and GLP (continuous). Participant identification number was included as a random effect to model inter-individual responses and account for the non-independence of observations in the repeated measures design of the study. Where interactions of interest were identified, post-hoc analysis were completed using the *emmeans* package [168].

To balance model parsimony and goodness of fit, the full model's effect estimates, standard errors, and p-values were inspected, and the model was simplified by first removing interaction terms (and retaining the variable as a main effect) of fixed effects with weak associations. Weak evidence was assessed by a combination of factors: odds ratios close to one (interpreted relative to the scale of the predictor), the width of the confidence intervals, and highest p-values. This backward stepdown variable selection approach was used given the convenience-based sample size and that previous SRSS data on a similar participant cohort is not available to inform what relative likelihood to expect [169]. After model simplification by removing interaction terms, main effects that did not contribute to the model were removed from the model [170]. Simpler models were compared to the more complex model via AIC, BIC, and likelihood ratio test [171]. If model fit improved with the simpler model, the simpler model was selected and the process of model simplification continued until model fit did not improve. If model fit did not improve with the simpler model, the more complex model was retained and reported. Day (7, 2, or 0) was always retained as a fixed effect in the final model due to conceptual importance.

After determining the final model, the proportional odds assumption was evaluated through visual inspection of empirical logits for cumulative probabilities at each threshold of the ordinal response (0–6) [171]. Where visual inspection indicated violations of the proportional odds assumption, the proportional odds model was retained to provide a unified, averaged estimate of the predictor's effect across all response levels. In these cases, results are interpreted as reflecting an average effect rather than threshold-specific associations. Multicollinearity was assessed by calculating the variance inflation factor between predictors. Linearity of continuous variables was assessed by adding quantile natural splines (0.05, 0.35, 0.65, and 0.95) to continuous variables (body weight and/or GLP) in the final model separately and then performing a likelihood ratio test comparing the final CLMM model with the spline model [171].

One participant did not register a total at competition and the mean cohort GLP (97.8) was imputed for this participant to enable analysis of all participants that completed the SRSS. Odds ratios were derived and reported by exponentiating the log odds co-efficient produced from the CLMM model.

Section 3: Results

The final sample included 53 participants (females = 26, males = 27) with an average GLP score of 97.8. There were 7 participants who placed first, and 11 participants who placed second or third in their respective weight class.

On average, participants decreased body weight by 0.39 kg between day 7 and day 2, and 1.44 kg between day 2 and day 0. Total body weight loss from day 7 to day 0 was 1.83 kg (2.5% of total body weight). The association between GLP score at competition and the magnitude of weight change between day 7 and day 2 was $\beta = 0.66$ (95% CI [-3.03, 4.36], $p = 0.72$). The interaction between day 2 to 0 weight change and sex was positively associated ($\beta = 3.38$, 95% CI [-0.22, 7.00], $p = 0.07$). Post-hoc analysis suggested a positive association of GLP with weight loss between day 2 and 0 for females ($\beta = 3.31$, 95% CI [0.36, 6.25], $p = 0.02$) but not males ($\beta = -0.08$, 95% CI [-2.51, 2.35] $p = 0.94$).

SRSS Q1 PPC

The odds of reporting a higher PPC response were lower on day 2 (OR = 0.54, 95% CI [0.26, 1.13], $p = 0.10$) and on day 7 (OR = 0.91, 95% CI [0.43, 1.92], $p = 0.80$) relative to day 0, respectively. The odds of reporting a higher PPC response were higher on day 7 relative to day 2 (OR = 1.67, (95% CI [0.81, 3.44], $p = 0.17$). The odds of reporting a higher PPC response increased as GLP increased (OR = 1.04, 95% CI [0.99, 1.09], $p = 0.07$). The odds of reporting a higher PPC response were lower as day 2 to 0 as relative body weight loss increased (OR = 0.74, 95% CI [0.58, 0.95], $p = 0.02$).

SRSS Q2 MPC

The odds of reporting a higher MPC response were lower on day 2 (OR = 0.35, (95% CI [0.16, 0.75], $p = 0.007$) and on day 7 (OR = 0.99 (95% CI [0.47, 2.08], $p = 0.97$) relative to day 0, respectively. The odds of reporting a higher MPC response were higher on day 7 relative to day 2 (OR = 2.76 (95% CI [1.32, 5.79], p = 0.007). The odds of reporting a higher MPC response increased as GLP increased (OR = 1.04, 95% CI [0.99, 1.09], p = 0.10). The odds of reporting a higher MPC response were lower as day 2 to 0 relative body weight loss increased (OR = 0.71, 95% CI [0.53, 0.96], p = 0.03).

SRSS Q3 EB

The odds of reporting a higher EB response were lower on day 2 (OR = 0.55, 95% CI [0.26, 1.16], p = 0.11) and on day 7 (OR = 0.69, 95% CI [0.33, 1.43], p = 0.32) relative to day 0, respectively. The odds of reporting a higher EB response were higher on day 7 relative to day 2 (OR = 1.24 (95% CI [0.61, 2.55], p = 0.54).

SRSS Q4 OVR

The odds of reporting a higher OVR response were lower on day 2 (OR = 0.35, 95% CI [0.17, 0.73], p = 0.001) and on day 7 (OR = 0.60 (95% CI [0.29, 1.25], p = 0.17) relative to day 0, respectively. The odds of reporting a higher OVR response were higher on day 7 relative to day 2 (OR = 1.96, 95% CI [0.91, 4.22], p = 0.08). The odds of reporting a higher OVR response increased as GLP increased (OR = 1.03, 95% CI [0.99, 1.07], p = 0.12). The odds of reporting a higher OVR response were lower as day 2 to 0 as relative body weight loss increased (OR = 0.85, 95% CI [0.69, 1.03], p = 0.10).

SRSS Q5 MS

The odds of reporting a higher MS response were higher on day 2 (OR = 4.66, 95% CI [2.26, 9.59], p = 0.0001) and on day 7 (OR = 3.40, 95% CI [1.65, 7.04], p = 0.001) relative to day 0, respectively. The odds of reporting a higher MS response were lower on day 7 relative to day 2 (OR = 0.73, 95% CI [0.37, 1.45], p = 0.37). The odds of reporting a higher MS response were higher as day 2 to 0 as relative body weight loss increased (OR = 1.19, 95% CI [1.01, 1.40], p = 0.03).

SRSS Q6 LOA

The odds of reporting a higher LOA response were higher on day 2 (OR = 3.37, 95% CI [1.21, 9.37], p = 0.02) and on day 7 (OR = 2.30, 95% CI [0.79, 6.67], p = 0.13) relative to day 0, respectively. The odds of reporting a higher LOA response were lower on day 7 relative to day 2 (OR = 0.68, 95% CI [0.26, 1.79], p = 0.44). There was a positive association between day 2 (relative to day 0) LOA responses and day 2 to 0 weight change (OR = 1.36, 95% CI [0.97, 1.93], p = 0.07). Post-hoc analysis suggested that as the magnitude of relative weight loss increased from day 2 to 0, the odds of a higher LOA response increased on day 0 (OR = 1.48, 95% CI [1.10, 1.99], p = 0.008) but not day 2 (OR = 1.08, 95% CI [0.82. 1.43], p = 0.40).

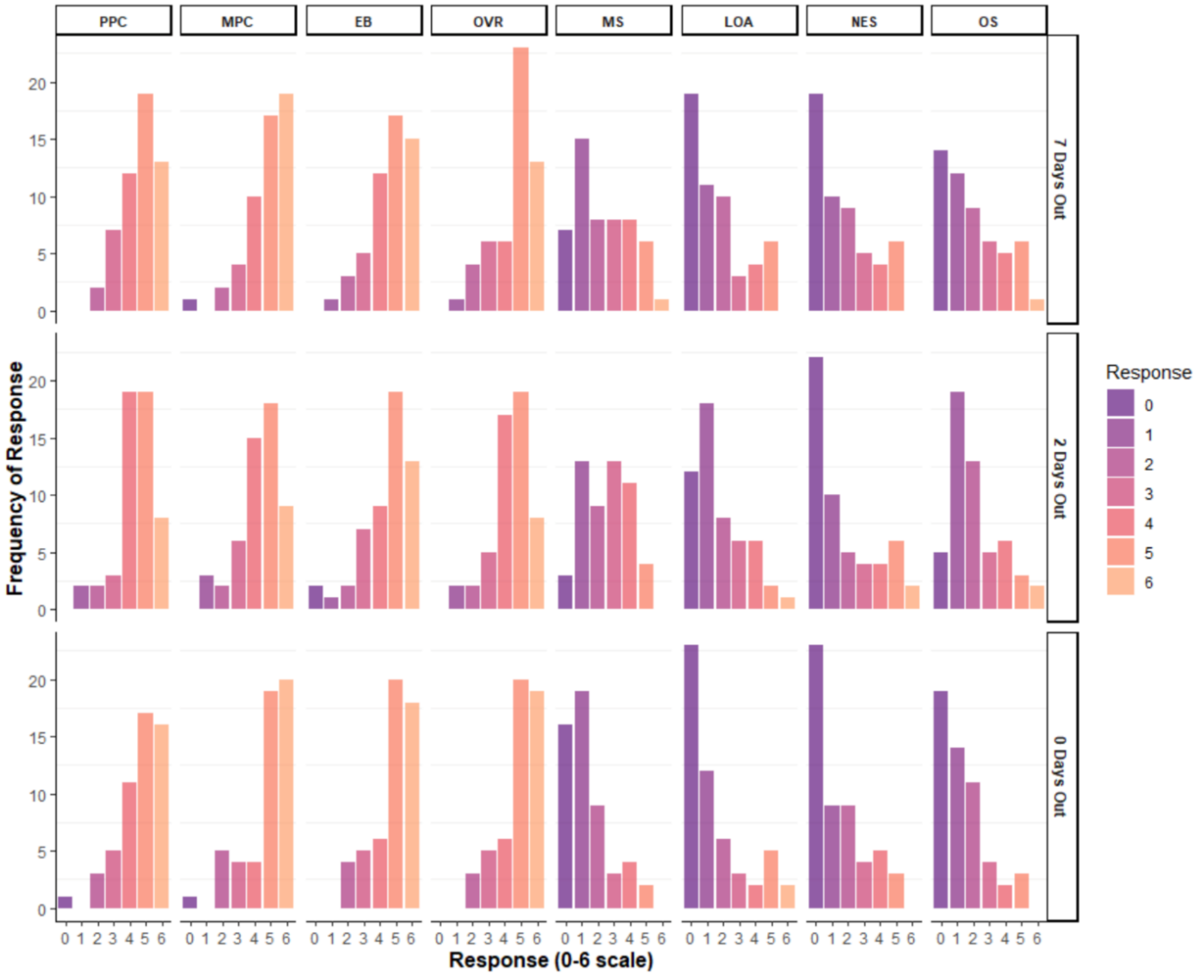
SRSS Q7 NES

The odds of reporting a higher NES response were higher on day 2 (OR = 1.23, 95% CI [0.59, 2.57], p = 0.58) and on day 7 (OR = 1.36, 95% CI [0.67, 2.79], p = 0.39) relative to day 0, respectively. The odds of reporting a higher NES response were higher on day 7 relative to day 2 (OR = 1.11, 95% CI [0.54, 2.27], p = 0.78). The odds of reporting a higher NES response decreased as GLP increased (OR = 0.96, 95% CI [0.92, 1.00], p = 0.06). There was a positive association between sex and day 2 to 0 body weight change (OR = 1.52, 95% CI [1.01, 2.30], p = 0.04). Follow up analysis revealed a positive slope for females (OR = 1.52, 95% CI [1.01, 2.29], p = 0.04) indicating that for every additional percentage point of relative body weight loss, the odds of a higher NES response increase 52%.

SRSS Q8 OS

The odds of reporting a higher OS response were higher on day 2 (OR = 4.71, 95% CI: [1.71, 13.00], p = 0.002) and on day 7 (OR = 3.65, (95% CI: [1.26, 10.53], p = 0.01) relative to day 0, respectively. The odds of reporting a higher OS response were lower on day 7 relative to day 2 (OR = 0.78, 95% CI [0.29, 2.06], p = 0.61). The odds of reporting a higher OS response were higher on day 0 as day 2 to 0 relative body weight loss increased (OR = 1.33, 95% CI [1.01, 1.74], p = 0.04).

Figure 4-1 SRSS response across three time points



Abbreviations: Physical Performance Capability (PPC), Mental Performance Capability (MPC), Emotional Balance (EB), and Overall Recovery (OVR). The subsequent four items measuring stress include Muscular Stress (MS), Lack of Activation (LOA), Negative Emotional State (NES), and Overall Stress (OS).

Section 4: Discussion

We explored the relationship between SRSS scores and the magnitude of body weight loss, sex, proximity to competition, and GLP in powerlifters competing at two World Championships. We report that (a) elite powerlifters can decrease subjective stress and promote recovery leading into competition, (b) powerlifters with higher GLP at competition are more likely to report better stress and negative emotional state scores, (c) higher relative magnitude of weight loss is associated with worse subjective stress and recovery scores, and (d) female powerlifters experience worse negative emotional state responses with higher relative weight loss. On average, participants lost 2.5% of total body weight from day 7 to 0, with most weight loss occurring in the final two days before competition (2%). Since most RWL methods induce body weight loss in the final days leading to competition, this pattern was expected. While we did not ask participants about their RWL methods, previous surveys on powerlifters indicate a combination of fluid manipulation and gut volume manipulation are used [2], which likely was also the case in the present sample. We explored the relationship between SRSS scores and relative body weight loss, proximity to competition, sex, and GLP. These categories were based on assumptions and observations from previous research in other weight class sports [156, 172] and the authors' powerlifting coaching experiences. Indeed, we observed associations between PPC, MPC, OVR, MS, LOA, and NES, with relative body weight loss. In this study, higher scores indicate that a specific measure fully applies, this means that the higher the score, the higher perceived state.

The present sample of elite powerlifters competing at the World Championships were more likely to experience higher recovery as their proximity to competition increased. The odds of reporting higher PPC, MPC, EB and OVR scores were lower on day 2 relative to day 0. On these four recovery items, powerlifters were 45 - 65% less likely to report a higher score for recovery on day 2 (relative to day 0), suggesting that the powerlifters perceived their physical capacity, mental capacity, emotional balance and overall recovery to be lower on day 2 compared to immediately before competition. Similar trends were also observed in stress-related measures, as MS, LOA, and OS were more likely to be lower (lower scores indicate lower perceived stress), suggesting that perceived stress levels declined closer to competition. The lower odds of recovery and higher odds of stress on day 2 compared to the day of competition align with existing research on pre-competition anxiety and subjective well-being peaking and diminishing after competition.[173, 174]. Therefore, it is unsurprising that as an athlete approaches competition, subjective well-being and recovery decreases while stress increases and these feelings are largely diminished after the athlete successfully weighed-in (day 0).

Relative body weight change in the two days before competition affected responses on five of eight subscales within the SRSS, generally indicating worse subjective recovery and stress as relative weight loss increased. The odds of scoring higher on PPC, MPC, and OVR were lower as more relative weight loss occurred between day 2 and on competition day, indicating worse recovery as acute relative weight loss in the 2 days before competition increased. Similarly, the powerlifters had higher odds of reporting higher MS and LOA (i.e., worse scores) scores with each additional percentage point of weight loss on competition day. Further, our data aligns with other research showing that with greater body weight loss, negative impacts on performance can be felt to a greater degree [14, 175]. Logically, lifters with only 2 hours to refuel could experience an even greater negative impact on PPC, scaling with lost relative body weight. In support of this contention, and in alignment with our findings, the impact of RWL on cognitive function and mental performance is well established [28], with some studies indicating a greater decrease in outcomes related to MPC as body weight loss increases [10, 176]. A second explanation for our findings could be that a lifter's mental state is impacted to a greater extent when they realize they must lose a large amount of body weight closer to competition from day 2 to day 0, despite having lost weight from day 7 to day 2. In the current study, higher subjective MS was more likely among powerlifters who lost more weight from day 2 to day 0. Further, the odds of higher LOA scores were greatest on day 0 rather than day 2, indicating that greater weight loss by day 0 likely contributes to more feelings of less motivation, energy, and enthusiasm on the day of competition. Body weight loss can lead to significant changes in biomechanics, such as altered joint angles and leverages, which may affect neuromuscular coordination [140, 144], possibly impacting the subjective experience of the final training sessions before competition which happens 2-3 days before competition leading to greater perceived LOA. Collectively, our data indicate that with more relative weight loss in the 2 days before competition, the participants were more likely to feel less recovered and more stressed on day 2 compared to day 0.

The powerlifters' subjective stress and recovery were also influenced by their competitive calibre, measured by GLP. Higher-calibre lifters perceived that they were more recovered and less stressed (NES), irrespective of the proximity to competition. The likelihood of higher responses for PPC, MPC, and OVR (indicating better recovery) increased per each additional unit of competitive calibre (1 GLP). Lifters with higher GLP scores had 5%, 4% and 3% greater odds of reporting higher recovery PPC, MPC and OVR scores, respectively. A similar trend was observed with NES, where higher GLP scores were associated with a 4% decrease in the odds of experiencing NES. Thus, collectively, as GLP increases (and competitors become more experienced), they may be better able to mitigate stress and manage bodyweight loss, resulting in greater perceived recovery. Elite powerlifters, either due to inherent traits, confidence in better established RWL methods, or simply due to repeated exposure, may be resilient to the negative perceptual impacts of RWL. It is also possible that the relationship between GLP and SRSS scores are bidirectional. While speculative, novice powerlifters may use less effective RWL strategies—and have less experience with the strategies—subsequently resulting in the RWL process negatively impacting performance, and thus, their GLP scores. Additionally, previous research measuring competitiveness through medal achievements found that powerlifters who competed more frequently were more likely to win medals while performing RWL [17]. The increased odds of winning while using RWL further support the hypothesis that familiarity with RWL may mitigate its potential negative effects. In support of this contention, higher level Judokas exhibit greater psychological resilience than their less competitive counterparts [177]. Finally, elite athletes in other sports also exhibit higher confidence levels than their novice counterparts; building self-confidence is a strategy that can be used to reduce pre-competition anxiety [178] which may explain the lower NES reported by the powerlifters of higher calibre.

Interestingly, we observed sex specific associations with SRSS scores, body weight loss and GLP. In female participants, each additional percentage of relative weight loss increased the odds of reporting higher NES scores by 52%, a pattern that was not observed in the male lifters. Similarly, some research reports female fighters tend to experience higher anxiety compared to their male counterparts [12, 177, 179, 180]. Further, there was a small interaction effect between GLP registered at competition, relative body weight loss between day 2 and 0, and sex such that greater weight loss was associated with higher GLP score at competition in female lifters. Specifically, as weight loss increased, GLP at competition increased for female powerlifters in our cohort but not males. This might be because on average, the female lifters in our cohort had lower GLP scores compared to the males (95 ± 12.9 and 100 ± 6.1 GLP at competition, respectively). Therefore, it is unclear whether we observed a true sex difference *per se* or whether the difference in GLP between male and female powerlifters in our sample influenced these observations.

A strength of our study is that all the participants were elite powerlifters competing at World Championships, offering valuable insights into the real-world practices of top-level athletes. Importantly, the effects of RWL in elite lifters may differ from those observed in lower level powerlifters, as noted in previous research [17]. Additionally, as opposed to a retrospective online survey, the data were collected in-person, in real-time, with the researcher at the event. These conditions allowed clarification of potential misunderstandings, likely reducing recall bias [181], and captured the lifters' immediate emotional responses, potentially increasing data accuracy [182]. Finally, rather than collecting data across multiple events of different levels, we believe the homogeneity of the competition environment reduced potential variability in the participants' emotional reactions [183]. Therefore, by focusing on lifters competing at the highest level—the IPF World Championship—we may have enhanced the reliability of our findings. Finally, the use of a validated, as opposed to a non-validated scale is notable, as relationships between such scales with performance can rival or even surpass that of relationships with lab-based physiological testing [184].

Our findings show that RWL may influence perceived stress and recovery, with certain effects (NES and GLP) more pronounced in female powerlifters than males. However, further work is needed to determine if this is truly a sex-specific effect. At the very least, it may be that powerlifters with higher GLP experience fewer negative effects from RWL than lower-calibre competitors. Therefore, we speculate that with regular practice and familiarity with RWL protocols, lifters may experience lower stress and higher recovery during the weight-making process. However, despite the strength of our research, certain limitations exist. A major limitation is the observational nature of this study, as we did not control for the specific RWL methods used. While participants may have experienced similar losses in BM, different RWL methods may disproportionately affect certain SRSS scores. For example, dehydration-based methods may significantly increase subjective mood scores, such as fatigue and confusion [185], compared to gut volume manipulation, which may be more tolerable [5]. Additionally, the unique training protocols followed by each powerlifter prior to competition (i.e., the use or non-use of a taper and subsequent differences in load, frequency and volume) introduce an uncontrolled variable, potentially contributing to differing levels of fatigue, possibly influencing SRSS scores. A final unexplored factor is travel distance: powerlifters travel from various parts of the world to compete, likely causing differing levels of circadian rhythm disruptions, sleep deprivation, and jetlag, all of which may affect scores [186]. Given these limitations, we encourage future researchers to explore these trends using experimental designs to better elucidate these relationships and to confirm or refute our conclusions.

The categories measured and analysed in this study—such as body weight change over time, GLP, and sex—were determined based on insights from previous research and anecdotal coaching experience. Given the exploratory nature of this study, our findings and conclusions should be considered tentative. Furthermore, with a relatively small sample size of 53 participants, it is possible that future results may differ if conducted with a larger cohort.

Nevertheless, based on the present data, we conclude that certain measures of readiness, including PPC, MPC, OVR, MS, and LOA, are influenced by relative body weight changes resulting from RWL. Consistent with previous research, our findings suggest that female lifters may experience a greater impact on these measures than their male counterparts, although this could also be related to competitive calibre.

Section 5: Practical Applications

Our current study provides an exploratory framework utilising a more detailed and robust approach to quantifying the impacts of RWL on subjective wellbeing across multiple time points as powerlifters approach competition. Our results suggest that elite powerlifters tend to have higher recovery and lower stress scores as they approach competition, but a greater magnitude of weight loss is associated with worse subjective stress and recovery scores. Female powerlifters also tend to experience worse NES scores at greater magnitudes of weight loss compared to their male counterparts.

For coaches and athletes, this might suggest 1) that if performing RWL is an unfamiliar practice, managing the total magnitude of weight loss can potentially mitigate negative subjective wellbeing and 2) presumably as powerlifters improve in calibre, practice and confidence in RWL could reduce the risk of negative impacts and could be used as a viable strategy to improve competitiveness. In addition, 3) female lifters should exhibit greater caution when practicing RWL as our research is in agreement with research in combat sports showing a greater degree of NES when practicing RWL. Lastly, 4) for the exercise scientist, our study should serve as a starting point to develop future studies for hypothesis testing.

Chapter 5 A 3-day low fibre diet with macronutrient manipulation induces repeatable, short term weight loss in resistance-trained men and women.

Submitted to Research Quarterly for Exercise and Sport

Prelude

As covered in Chapter 4, better recovery scores and lower stress scores in the SRSS were reported by lifters approaching competition and elite lifters also reported better perceived recovery and stress scores. However, neither Chapter 3 nor 4 established normative BM loss ranges for specific RWL methods, which was identified in Chapter 2 as a critical gap in the research. Thus, the purpose of Chapter 5 was to evaluate the efficacy and repeatability of LGV to induce RWL. Importantly, a LGV does not require dehydration, and therefore may pose less risk to performance than other RWL methods, making it an important target for research. However, given that gut motility differences may occur across different time points and differ by biological sex, this investigation of LGV used a repeated measures crossover model in both males and females to assess the consistency and repeatability of BM losses. The findings serve to document expected BM losses and describe their repeatability to inform practitioner and athlete expectations when using an LGV to induce RWL.

Section 1: Introduction

Powerlifting is a weight class-based strength sport and the methods of BM manipulation used by coaches and athletes to gain a competitive edge are anecdotally influenced by combat sport. However, powerlifting-specific research on weight cutting is scarce; to the authors' knowledge [15] survey papers have been published on the topic [2, 15, 17]. These papers demonstrated a higher prevalence (%) of low fibre diet usage among powerlifters than among Olympic combat sport athletes (26.5% vs 12.7%) [187]. Further, despite the scarcity of scientific research in this area, 83% of powerlifters reported performing RWL and this spanned from amateur- to elite-level [2]. The most common methods reported by powerlifters are water loading and water cutting followed by low fibre diets, which warrants further investigation [2].

As a RWL strategy in weight class-based sport, a low fibre diet is hypothesised to result in acute BM loss as discussed in combat sport literature [156], although there is no empirical data that yet supports this specific hypothesis. However, in theory, this intervention should reduce the mass of undigested food and water stored in the intestines via a reduction in fibre (to <10g/day) [188]. Notably, this method has been used successfully as a preparation method for colonoscopy and colorectal surgery [189], albeit via more invasive medical procedures such as the usage of bisacodyl and sodium phosphate, which can lead to dehydration [190], which may not be suitable for the athletic environment.

In an athletic environment, a survey conducted by Reale and colleagues reported that 3-16% of Olympic combat sports athletes perform some form of fibre reduction [187] as part of their RWL strategy Further, Reale and colleagues observed BM losses of 3.3 % when using fibre reduction in concert with a water loading and restriction protocol [187]. Moreso, Foo and colleagues recently demonstrated that a 4-day low fibre diet in isolation resulted in a 0.7% reduction in BM [5]. However, in the case of Reale and colleagues, fibre reduction was used in concert with other approaches, and no change in macronutrient composition was made in either study. Further, Foo and colleagues reported that BM loss peaked 3 days (day 4) into the low fibre diet and increased slightly after 4 days (day 5), presumably due to a low-fibre diet inducing constipation. Thus, more data is needed to specifically examine fibre reduction, and macronutrient manipulation in concert, without water manipulation, to determine the ideal implementation time course of such a diet for weight class-based sports application.

Of further importance, is that the aforementioned study conducted by Foo and colleagues is also limited due to being conducted solely in males and thus, its findings may not be as applicable to female athletes' due potential sex differences such as slower GI motility [191]. An additional limitation is that Foo and colleagues performed their collection as a single time series (not a repeated measure study) which limits the assessment of BM loss variability when using a low fibre diet. Lastly, as is anecdotally common among powerlifters, we modified our experimental low fibre diet to include both a fibre reduction and a reduction of carbohydrate (CHO) while being in an isocaloric state by increasing fat intake - from here on be defined as an LGV diet - may induce greater BM losses by further reducing food volume due to the density of calories provided by fat compared to CHO (9 kcals/g v 4kcals/g). This reduction in CHO is herein termed the cumulative CHO deficit and is explored as a predictor of body weight loss.

Due to the limitations in the extant research, we conducted a study to assess the effect of a LGV diet on BM in strength trained males and females over 3 days, using a crossover design. We hypothesised that a 3-day LGV diet would result in significant BM losses, that the losses would be similar between crossover arms, similar between males and females, and be slightly higher (0.8-1% of BM) than the BM losses reported in prior research when a low fibre diet was used in isolation.

Section 2: Methods

Participants

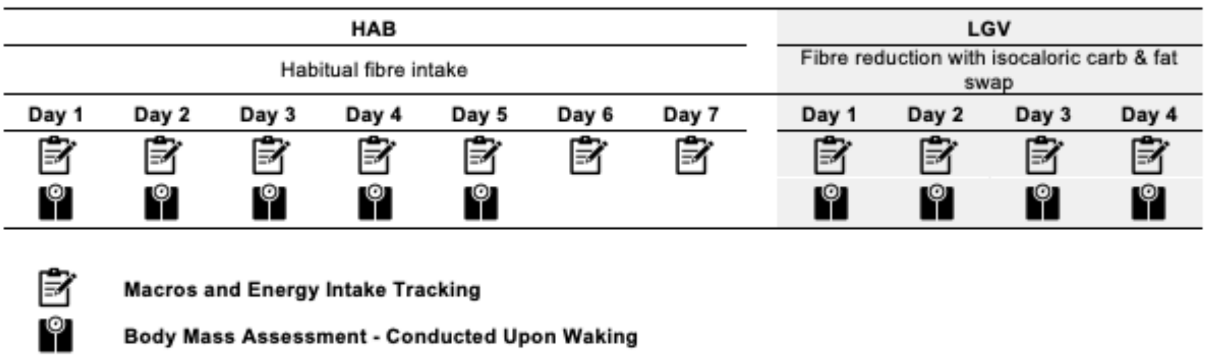
13 participants 8 males and 5 females mean age of 29.6±3.7 years and weight76.33 ±12.37kg) completed the full protocol with no dropouts. Participants were required to be RT athletes (at least a 1.5x bodyweight squat and 1x bodyweight bench press and two years of training experience), and self-report that they had some prior experience with nutrition tracking, specifically calories and macronutrients. Participants were then requested to provide prior records of their experience tracking nutrition using their preferred nutrition tracking app so the lead researcher could confirm their basic proficiency. All participants reported that they were free from food allergies, GI diseases, or any form of illness. Females were requested to perform the study at similar phases of their menstrual cycle and not to alter the usage (or lack thereof) of hormonal contraception. Before beginning this study, all participants provided informed consent. This study was approved by the Auckland University of Technology (AUT) ethics committee; ethics number 20/203.

Study design

An outline of the study design is shown in Figure 5-1. Participants were asked to consume and report their habitual diet (HAB) across a baseline period of 5 days. Participants then performed a LGV diet for 3 days consisting of a reduction in fibre intake by omitting habitual high-fibre foods along with a 60% reduction in habitual CHO consumption while matching energy intake through an increase in dietary fat. Participants recorded their BM for nine days, the first five days were used to evaluate habitual body weight, and the second four days to assess the impact of the LGV diet. After the first trial, participants had a minimum 3-week washout period to restore regular eating habits and BM before repeating the second arm of the crossover.

After the completion of the first LGV diet, participants had a minimum 3-weeks washout period in which they resumed their HAB before performing the second crossover arm. For the second trial, participants performed the LGV diet identically to the first trial. Participants started with a 5-day HAB, followed by a 3-day LGV diet again. At the end of the second trial participants were also asked via a written question, “yes or no” if they would repeat this diet to induce RWL should the need arise to assess feasibility. The main outcome measures were dietary intakes and BM changes.

Figure 5-1 Timeline of study (Trial below repeated once after washout period)



Dietary Intake Assessment and Intervention

Participants tracked their macronutrients on their respective smart phone app-based nutrition trackers while logging both macronutrient consumption and food information into an online spreadsheet during the entire 9-day period. Participants used different apps based on what they were previously accustomed to (to ensure familiarity and consistency with prior tracking experience) and were instructed to use the same software for both LGV diet crossovers. During the first five days, energy intake, CHO, protein, fat, and fluid consumption were tracked, and a food log was written to assess the participants' HAB. To reduce fibre intake, participants were given detailed individualized instructions on what to omit from their HAB as recorded in the food log before starting the LGV diet. A food list was provided to participants to ensure that during the length of the LGV diet, fibre-rich foods were omitted (appendix D). Participants were given the opportunity to ask questions about the LGV diet and could contact the researcher at any point in the study to discuss food choices. After completing the first LGV trial, participants were instructed to replicate the food choices in the second LGV trial as similarly as possible.

Guidelines to implement a 3-day LGV diet were given for each participant based on dietary records during their initial 5-day HAB period. The LGV diet consisted of removing all forms of fibre from fruits, vegetables, and complex CHOs. The participants were instructed to maintain the same total protein intake and fluid intakes/types as HAB period while reducing CHO intake by 60%, with an isocaloric exchange matching this energy reduction via an increase in fat intake. Participants were asked to continue to track their nutrition and provide a food log for continuous assessment during the study and were encouraged to contact the researcher should they have any questions or doubts regarding the implementation of the LGV diet.

BM

BM was recorded in identical conditions the morning after the participant's first urination and when possible, defecation. This measurement was taken completely unclothed with the participants' respective personal scales. The participants were instructed to use the same scale across the entire length of both trials. BM was measured for five consecutive days during the HAB and three days during LGV. BM was then recorded in a spreadsheet shared with the researcher for monitoring. The average BM over five days of HAB was then compared with the BM logged on day one (LGV1), two

(LGV2) and three (LGV3) of the LGV after participants completed these three consecutive days of the diet. The BM change was reported as relative (%) and absolute (kg) BM loss.

Statistical analysis

Normality of the data was assessed via graphical inspection and standard skewness/kurtosis criteria [192, 193]. Descriptive data are reported as group means. Primary outcomes were absolute and relative body weight change, and daily intake of macronutrients (protein, CHO, and fat), total energy (kcal), and water.

Cumulative CHO deficit (g) was calculated for each LGV condition as the total gram difference between habitual CHO intake and the intake recorded on each day of the LGV diet. For example, cumulative deficits were computed as: LGV1 = (HAB − LGV1), LGV2 = (HAB − LGV1) + (HAB − LGV2), and LGV3 = (HAB − LGV1) + (HAB − LGV2) + (HAB − LGV3). This variable was used as a continuous predictor to explore potential dose–response relationships between CHO restriction and changes in body weight.

Linear mixed-effects models were used to examine the effects of condition (4 levels: HAB, LGV1, LGV2, LGV3) and trial (2 levels: Trial 1, Trial 2) on absolute and relative weight change, and on dietary intake variables. Where theoretically justified, interaction terms between condition, trial, and cumulative CHO deficit were included. A maximal random effects structure [194] was initially specified, including random intercepts for participant ID and random slopes for condition and cumulative CHO deficit. Where models failed to converge, simplification proceeded in a stepwise manner: first by removing random slopes, then by excluding the interaction term. Random intercepts for participant ID were always retained to account for within-subject dependency.

For models assessing macronutrient, energy, and water intake, condition (HAB vs LGV) and trial number were included as fixed effects (with interaction term), with participant ID as a random intercept. All models were fit using restricted maximum likelihood.

Model residuals were inspected visually and determined to be approximately normally distributed. Homoscedasticity and linearity were checked by plotting residuals against fitted values and predictor variables. Multicollinearity among predictors was assessed via variance inflation factors. Influential observations were assessed using Cook's distance and standardized difference in beta co-efficient. Observations were considered influential if Cook's distance exceeded the threshold for the 50th percentile of the F-distribution with degrees of freedom [195]:

$$df=(k+1,n-k-1)$$

or if standardized difference in beta co-efficient values exceeded 1 [196]

Where significant effects were observed, post-hoc pairwise comparisons were conducted, with Holm-Bonferroni correction applied for multiple testing. Statistical significance was defined as $\alpha \leq 0.05$.

All analyses were performed in R (version 4.3.3), using the *lme4 [197]emmeans [198]*, and *esvis* packages for modelling and effect size estimation. Model assumptions and influential cases were assessed using the *performance [199]* and *influence.ME [200]* packages, respectively. Data and code are available on the Open Science Framework (https://osf.io/ruqfe/).

Section 3: Results

Dietary intake

Protein

Protein intake was similar between HAB and LGV (152 and 156 g, respectively; p = 0.32) and between trial 1 and 2 (156g and 152g, respectively, p = 0.20).

CHO

CHO intake was significantly higher in HAB compared to LGV (276g and 119g, respectively; $p < 0.0001$). There was no significant effect of trial ($p = 0.49$), or interaction between condition and trial ($p = 0.93$).

Fat

There was a significant increase in fat intake from HAB to LGV (80g and 149g, respectively; $p < 0.0001$). There was no significant effect of trial ($p = 0.85$), or interaction of condition and trial ($p = 0.72$).

Total energy intake

Total energy intake was similar between HAB and LGV (2428 kcal and 2442 kcal, respectively; $p = 0.70$). There was no significant main effect of trial ($p = 0.15$), or interaction of condition and trial ($p = 0.45$).

Water

Water intake was similar between HAB and LGV (3.2 litres and 3.2 litres, respectively; $p = 0.91$). There was no significant main effect of trial number ($p = 0.10$), or interaction of condition and trial ($p = 0.30$).

Table 5-1 Descriptive table of macronutrients

Trial	Nutrients	5-DAY HAB AVERAGE	LGV 1	LGV 2	LGV 3	LGV Average	% Change
Trial 1	**Protein (g)**	155.1	158.1	157.6	153.4	156.4	0.79%
	Carbs (g)	272.3	124.9	123.3	122.5	123.6	-54.62%
	Fat (g)	84.9	146.1	149.9	149.4	148.5	74.89%
	Energy (kcal)	2471.7	2448.5	2470.8	2447.5	2455.6	-0.65%
	Fluids (L)	3.6	3.3	3.2	3.2	3.3	-9.65%
Trial 2	**Protein (g)**	148.2	158.9	153.5	153.7	155.4	4.86%
	Carbs (g)	249.5	117.8	114.8	113.2	115.3	-53.78%
	Fat (g)	118.1	148.7	150.0	149.9	149.5	26.60%
	Energy (kcal)	2389.0	2445.3	2423.7	2417.5	2428.9	1.67%
	Fluids (L)	3.0	3.1	3.3	3.1	3.2	7.12%

Repeatability

For relative BM change, there was no significant main effect of trial (p = 1.00) or interaction between trial and LGV1 (p = 0.68), LGV2 (p = 0.43), or LGV3 (p = 0.13).

For absolute BM change, there was no significant main effect of trial (p = 1.00) or interaction between trial and LGV1 (p = 0.71), LGV2 (p = 0.47), or LGV3 (p = 0.20).

Relative BM change

Compared to habitual body weight, relative BM change was significantly lower at LGV1 (-0.52%, 95% CI [-0.25, -0.80], p = 0.0003), LGV2 (-0.87%, 95% CI [-0.51, -1.25], p = 0.00001), and LGV3 (-1.49%, 95% CI [-1.01, -1.98], p < 0.0001). Compared to LGV1, BM loss was not significantly higher at LGV2 (-0.35%, 95% CI [-0.02,0.72], p = 0.07), but was at LGV3 (-0.96%, 95% CI [0.46, 1.47], p < 0.0001). Compared to LGV2, relative BM loss was significantly higher at LGV3 (-0.62%, 95% CI [-0.23, -0.99], p = 0.0003). Cumulative CHO deficit was not a significant predictor of relative BM change (-0.00001%/g, 95% CI [-0.0009, 0.0008], p = 0.88).

Absolute BM change

Compared to habitual BM, absolute BM loss was significantly more at LGV1 (-0.34kg, 95% CI [-0.11, -0.56], p = 0.004), LGV2 (-0.56kg, 95% CI [-0.26, -0.86], p = 0.0006), and LGV3 (-0.95kg, 95% CI [-0.55, -1.35], p = 0.00002). Compared to LGV1, absolute BM loss was not significantly higher at LGV2 (-0.22kg, 95% CI [-0.52, 0.09], p = 0.25), but was at LGV3 (-0.62kg, 95% CI [-1.03, -0.2], p = 0.001). Compared to LGV2, BM loss was significantly higher at LGV3 (-0.40kg, 95% CI [-0.70, -0.1], p = 0.005). Cumulative CHO deficit was not a significant predictor of absolute BM change (-0.004g/kg, 95% CI [-0.0011, 0.0003], p = 0.26).

Sensitivity analysis

The data from one participant was identified as having a Cook's distance greater than the threshold for relative and absolute weight change (h = 1.69 and 1.97 vs 0.87, respectively). For the same participant, difference in beta co-efficient values were greater than 1 for all model predictors.

Removing this outlier from the analysis altered the results. For relative BM change, and compared to habitual BM, removal of the outlier reduced the weight change estimates for LGV1 (-0.34%, 95% CI [-0.05, -0.64], p = 0.02), LGV2 (-0.42%, 95% CI [-0.01, -0.83], p = 0.05), and LGV3 (-0.88%, 95% CI [-0.32, -1.45], p = 0.001), and cumulative CHO deficit became a significant predictor of relative BM change (-0.002%/g, 95% CI [-0.0005, -0.003], p = 0.01). For absolute BM change, and compared to habitual BM, removal of the outlier reduced the weight change estimates for LGV1 (-0.16kg, 95% CI [-0.40, 0.07], p = 0.17), LGV2 (-0.13kg, 95% CI [-0.47, 0.20], p = 0.44), and LGV3 (-0.38, 95% CI [-0.84, 0.08], p = 0.11), and cumulative CHO deficit became a significant predictor of absolute BM change (-0.002g/kg, 95% CI [-0.003, -0.001], p = 0.001).

Table 5-2 Individual BM Changes Across Days 1-5 of HAB and Days 1-3 of LGV (Trial 1)

Participants (females)	HABITUAL						Low Gut Volume				
	Day 1	Day 2	Day 3	Day 4	Day 5	Average	Day 1	Day 2	Day 3	Average	% Loss
1	69.0	69.5	69.7	69.3	69.4	69.4	68.9	68.8	68.1	68.6	1.88%
2	60.1	60.1	60.2	60.3	60.3	60.2	60.0	60.0	59.7	59.9	0.84%
3	68.4	68.1	68.8	68.8	68.8	68.6	68.1	67.8	67.3	67.7	1.90%
4	62.6	63.1	62.7	62.7	62.8	62.8	62.3	61.8	61.6	61.9	1.91%
5	52.7	52.4	52.4	52.4	52.2	52.4	52.1	52.0	51.6	51.9	1.53%
Participants (males)											
6	83.4	83.0	83.7	83.7	83.0	83.4	82.8	81.4	81.2	81.8	2.64%
7	76.5	76.5	76.5	76.2	76.2	76.4	75.6	75.6	75.2	75.5	1.57%
8	91.0	90.2	90.8	90.3	90.5	90.6	89.7	90.0	89.9	89.9	0.77%
9	84.8	84.7	84.9	84.7	84.8	84.8	83.7	83.2	83.0	83.3	2.12%
10	96.2	96.2	95.4	95.7	95.7	95.8	95.7	95.7	94.6	95.3	1.25%
11	83.4	83.3	83.8	84.3	84.4	83.8	83.8	82.8	83.1	83.2	0.84%
12	95.8	95.2	95.2	95.3	95.2	95.3	95.2	94.6	93.8	94.5	1.57%
13	68.4	68.2	68.0	67.9	68.0	68.1	67.9	67.9	65.7	67.2	3.52%
Mean (N=13)	76.33	76.19	76.32	76.28	76.25	76.28	75.83	75.51	74.98	75.44	1.72%
SD	12.37	12.33	12.36	12.35	12.34	12.35	12.42	12.39	12.45	12.42	0.89%

Table 5-3 Individual BM Changes Across Days 1-5 of HAB and Days 1-3 of LGV (Trial 2)

	HABITUAL						Low Gut Volume				
Participants (females)	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Average**	**Day 1**	**Day 2**	**Day 3**	**Average**	**% loss**
1	69.4	69.0	69.3	69.4	69.2	69.3	69.0	68.4	68.7	68.7	0.72%
2	62.3	62.3	62.3	62.3	62.1	62.3	61.8	61.8	61.2	61.6	1.79%
3	68.1	67.6	67.7	68.2	68.3	68.0	67.8	67.5	67.4	67.6	0.88%
4	63.5	63.5	63.5	63.2	63.5	63.4	63.2	63.1	62.5	62.9	1.42%
5	52.1	52.4	52.3	52.4	52.5	52.3	52.2	52.1	51.7	52.0	1.15%
Participants (males)											
6	79.8	80.0	80.0	80.3	80.0	80.0	79.3	79.0	78.3	78.9	2.13%
7	76.5	77.2	76.6	76.5	76.8	76.7	76.4	76.3	76.2	76.3	0.65%
8	91.5	91.6	91.0	91.2	91.0	91.3	91.3	91.0	89.6	90.6	1.86%
9	85.9	85.9	85.9	85.9	86.4	86.0	85.1	85.3	84.9	85.1	1.28%
10	94.2	94.6	94.7	94.4	95.0	94.6	94.5	93.2	92.5	93.4	2.22%
11	82.4	83.6	83.3	83.5	83.8	83.3	83.3	82.7	82.9	83.0	0.48%
12	94.6	94.9	94.3	94.0	94.5	94.5	93.7	93.8	93.4	93.6	1.16%
13	66.8	66.8	66.8	67.0	67.3	66.9	66.2	66.3	65.8	66.1	1.64%
Mean (N=13)	75.93	76.11	75.98	76.02	76.18	76.05	75.68	75.42	75.01	75.37	1.35%
SD	11.97	12.00	11.98	11.99	12.01	11.99	12.02	12.01	12.07	12.03	0.63%

Subjective perception of diet and tolerability

When asked "would you be willing to use a LGV diet if the need to reduce acute BM arises" 12 out of 13 participants responded, one participant did not. All 12 responses were "yes."

Section 4: Discussion

Prior studies evaluated either the effects of fibre reduction [5] or a combination of fibre reduction with fluid manipulation [127], while the current study was the first to evaluate the effect of combining a reduced fibre and CHO diet in an isocaloric state. Broadly, we observed that an isocaloric reduction of fibre and a 60% reduction in CHOs across 3-days resulted in a 1.4%-1.7% loss in BM. The initial hypothesis was validated as a 3-day LGV diet was effective in reducing acute BM. However, the magnitude of BM loss exceeded our initial expectation as it nearly doubled BM losses of 0.8-1% observed in prior literature [5]. Further, a BM reduction of 1.4%-1.7% was observed across both trials. These findings demonstrate both the efficacy and consistency of a LGV diet for inducing RWL. Notably, there was a small but non-significant ($p = 0.47$) difference in BM lost between the first and second trial between males and females, with females losing of 0.2% and 0.1% less than males, respectively. Interestingly, all 12 participants (one did not respond) reported that they would be willing to perform a LGV diet to reduce acute BM in the future should the need arise. Thus, from a practical perspective, reducing fibre rich foods from HAB may serve as a better RWL strategy for athletes participating in weight-class restricted sport with a smaller amount of BM to lose than water restriction, as a LGV diet likely avoids the potential negative impact on performance from dehydration induced losses in BM [156, 201].

A novel element of our study was the instruction to reduce relative CHO contribution to the diet while matching energy intake through an increase in dietary fat. While Foo and colleagues only reduced participants' fibre, we swapped CHO for fat, leveraging energy density to minimise food weight. Since a single gram of fat contains 9 kcal compared to only 4 in CHO, this substitution may allow additional reductions of food weight without impacting overall energy intake. We termed this macronutrient swap as the cumulative CHO deficit and indeed, when comparing the present data to Foo and colleagues where participants only restricted fibre, the participants in our study reduced CHO by 54% during the LGV diet, which presumably resulted in the additional 0.6%-0.9% observed BM loss. However, our analysis revealed the cumulative CHO deficit failed to predict absolute or relative BM change, but deeper analysis indicated this initial lack of a relationship was due to an outlier.

This outlier was identified as their data exerted a disproportionate influence on model estimates and altered the interpretation when omitted. This participant reported the highest habitual relative dietary CHO intake in the sample (~6.6g/kg BM, compared to a cohort average of 3.6g/kg). In addition, this participant recorded a pattern of weight change across the LGV diet that diverged from the sample trend. Specifically, the participant exhibited no change in BM at LGV1 (trial 1 = 0.0 kg; trial 2 = –0.04 kg), followed by a relatively larger decrease at LGV2 (trial 1 = –0.6 kg; trial 2 = –1.04 kg), and a smaller loss again at LGV3 (trial 1 = –0.4 kg; trial 2 = –0.7 kg), relative to their habitual weight. In contrast, the sample progressive declined in BM across the LGV diet phases (LGV1 = –0.33 kg; LGV2 = –0.55 kg; LGV3 = –0.95 kg). It is possible that, because of this participant's high absolute baseline CHO intake, the standardized 60% CHO reduction during LGV was insufficient to produce the same degree of weight loss observed in other participants. Notably, even after the reduction, their CHO intake during LGV (~2.9 g/kg) may still represent a relatively moderate dietary

CHO intake. These findings highlight the need for future research to explore whether individuals with higher habitual CHO intakes may require greater relative reductions to achieve comparable weight loss outcomes during LGV diets with concomitant CHO restriction.

Removing the influential participant resulted in a reduction of the estimated effects for both relative and absolute weight loss across LGV 1-3. In addition, cumulative CHO deficit became a significant predictor in both models ($p < 0.05$). Exploratory visualisation indicated that the outlier was likely contributing positive leverage on differences between conditions (i.e., HAB vs LGV 1-3) and given the outlier's non-linear decrease in BM, their removal from the analysis attenuated the condition estimates. Furthermore, exploratory analyses indicated collinearity between the condition variable and cumulative CHO deficit. Thus, excluding the outlier may have shifted explanatory variance from the categorical condition variable to the continuous CHO deficit variable. These outcome changes suggests that day-based effects during the LGV diet (i.e., LGV1 to LGV3) may function as a proxy for cumulative CHO deficit (or vice versa).

Generating a cumulative CHO deficit by making an isocaloric exchange with dietary fat is a simple method that may promote further acute BM losses that is unlikely to pose a risk for strength performance when compared to other aggressive methods that induce dehydration or reduce energy intake [46]. Specifically, prior research on powerlifters and weightlifters by Greene and colleagues [142] demonstrated that a reduction in CHO to ketogenic levels for three months did not significantly impact strength compared to a mixed macronutrient diet with similar energy intakes. Muscle glycogen utilisation and depletion is intensity and site (both to the specific muscle fibre type and intramyocellular location) specific [202]; hence, the typical taper week for a powerlifter which occurs in the final week leading into competition where weight manipulation also occurs (such as the use of a LGV) [203] is unlikely to require a high CHO intake or to have its performance limited by CHO reduction [204]. Therefore, considering the three-day CHO restricted - but non-ketogenic - nature of the present LGV diet, we believe the probability of a negative impact on strength is low.

Although our study is not the first to assess the efficacy of a low fibre diet, it is the first to investigate the efficacy and repeatability of a LGV diet over a span of two repeated 3-day periods - one day shorter than a previous study conducted by Foo and colleagues. The mean BM loss of participants observed by Foo and colleagues was highest after 3 days of a low fibre diet, as some participants' BM began to increase on the fourth day of the low fibre intervention, presumably due to the reduced stool frequency, increased hardness and inter-individual variability of gut transit time [205]. Our findings confirm that after 3 days of LGV, participants had the lowest BM when compared to HAB and 3 days was sufficient to induce a significant acute BM reduction. Further, we assessed a mixed-sex cohort and evaluated sex differences, while Foo and colleagues only assessed males. The inclusion of females is important, because despite the theoretical possibility of sex differences due to females [206] having lower GI motility [191], no prior investigations compared sexes. Notably, the present findings indicate that any differences in BM loss following a LGV diet between sexes are likely minor.

In agreement with Foo and colleagues [5] our study provides further confidence that an LGV is not only an effective method to induce RWL, but a feasible one, as 100% of the participants who responded said that they would use an LGV again. Further, our study is the first to evaluate the repeatability of an LGV diet. The LGV diets in both crossover arms induced RWL, as both males and females lost 1.2%-1.7% of BM on both occasions. A major distinction in our study is that we did not specify a fixed target amount of fibre that was required for our participants to omit. This may be a limitation, but it also provides greater ecological validity and ease of implementation as research indicates that athletes fibre intakes vary (from 13-29g per day) and differ by sport and competitive level [207-209]. Unfortunately, there are no data on the fibre intakes of powerlifters, and further research is needed to determine typical amounts, which may potentially differ by weight class, region, competitiveness, and age. Importantly, among powerlifters who consume low-fibre diets, specifying a fixed amount of fibre instead of adjusting fibre based on their HAB may lead to an athlete consuming more fibre than usual. Thus, from a practical perspective, our findings provide support that BM can be reduced without the need to track fibre precisely, allowing coaches and weight-class restricted athletes to employ the simpler RWL strategy of omitting fibrous-rich food instead of tracking grams of fibre specifically. While some may view the lack of standardisation of a specific amount of fibre as a limitation, this study purposefully accommodated a more practical and ecologically valid way of reducing BM without the need to track fibre intake to enhance its translational nature to practice.

However, our study is not without limitations. Notably, no performance measures were taken. While there is no reason to expect an LGV to acutely impact strength performance, empirical confirmation is needed to establish complete certainty that this is indeed the case. Baseline CHO intake may also confound the BM loss due to cumulative CHO deficit, which might not be effective with higher CHO intakes (6.6g/kg bodyweight). Lastly, sample size may also be another limitation as we observed a small but non-significant difference in total BM loss in trial two compared to one; however, this likely occurred due to several participants starting the second trial with a slightly higher bodyweight. This higher BM could have been due to these participants having more food bulk in their GI tract; therefore, due to the practical nature of our study where fibre was not measured or recommended, the removal of fibre-rich foods may have led to a greater loss of BM in the second trial. Thus, more research with larger sample sizes which measures relevant performance outcomes is recommended.

In conclusion, by omitting fibre-rich foods in conjunction with an isocaloric swap of CHO for fat for 3 days male and female athletes can reliably reduce BM by 1.2% to 1.8% after 3 days.

Section 5: Practical Applications

The current study demonstrates the repeatability of a fibre reduction manipulation diet for weight-class restricted athletes. Our findings show that 1) athletes can use a LGV diet to induce 1.2%-1.8% of BM loss without needing to track fibre intake. We have also shown 2) the repeatability of BM loss, which allows athletes to be confident in their ability to lose BM as they prepare for competition. Lastly, 3) both males and females can utilise this method of RWL successfully to induce BM loss.

Considerations for the athlete include ensuring an adequate reduction of CHO intake if their habitual CHO intake is high. Female athletes would also need to be aware of their menstrual cycle, as this might influence total BM loss. Additionally, since an exact fibre reduction was not specified, the ranges of BM loss may vary based on habitual fibre intake and should be taken into consideration.

Collectively, this approach can be used as a method of RWL to reduce a moderate amount of BM with minimal impact on training performance, compared to other RWL methods that induce an energy deficit or dehydration.

Chapter 6 The impact of dehydration via heat exposure at different time points on resistance training performance.

Submitted to the European Journal of Sport Sciences

Prelude

Chapter 5 demonstrated that an LGV can induce up to 1.6% BM loss which was repeatable across differing time points in males and females. A 1.6% BM loss primarily from food mass would arguably categorise LGV as a less “aggressive” and risky method of RWL. However, at higher levels of competitiveness, dehydration via heat exposure is used to induce RWL as was seen in Chapter 3. Dehydration via heat exposure risks the combined negative impact of both dehydration and heat stress. Thus, the goal of Chapter 6 was to investigate how to best minimise any negative performance impact of dehydration via heat exposure on strength and power performance. Thus, this study investigated the timing of heat-induced PD in a lab-based setting, manipulating its timing to either be 1) further from weigh-ins and performance testing, increasing time spent dehydrated or 2) closer to weigh-ins, decreasing time spent dehydrated but also placing heat stress closer to performance testing. For athletes or practitioners considering the use of heat-induced PD as a RWL strategy, these findings help to set expectations regarding potential negative impacts on performance, and may inform potential strategies to mitigate such impacts.

Section 1: Introduction

RWL is common practice for weight-class restricted athletes especially in combat sports [187]. There are many RWL methods, including fluid manipulation, a reduction of food volume and fasting, and other methods for “making weight” leading into competition [39]. Amongst them, PD is also a common practice among competitive athletes in weight-class sports [65]. Active dehydration is when sweating is induced by engaging in some form of exercise or activity, while PD can be defined as the dehydration process, typically via sweating, created through some form of heat exposure while the athlete remains at rest.

Powerlifting is a weight-class strength sport in which maximal strength in the three competition disciplines, the barbell squat, bench press, and deadlift dictate performance. Like combat athletes, powerlifters also use similar RWL methods [2]. Powerlifters use of these RWL methods requires balancing the potential benefits of reduced BM (necessary to make weight) with the detrimental impacts of hypohydration on muscular function [210]. Consequently, there are powerlifters who employ PD [2, 17], but the impact of PD on powerlifting performance is yet unclear. Schoffstall and colleagues examined the effects of sauna-induced PD resulting in 1.5% BM loss on 1RM bench press in resistance-trained (RT) males. The authors reported a decrement in strength immediately post-dehydration, but strength was restored two hours after rehydration [4]. While relevant to the bench press discipline in powerlifting, this study did not include any metric of lower body strength which could inform the potential impact of PD on squat or deadlift performance.

Another element of PD that is less understood, is the impact of PD occurring in the morning (AM) versus evening (PM). Powerlifters have different weigh-in times depending on the competition schedule, their weight class, and/or the federation's rules, resulting in athletes performing PD either in the AM or PM. Depending on the choice to perform PD in the AM or PM, it may prolong the time the athlete spends in a state of dehydration, which may further impact performance [211, 212]. Likewise, this choice also changes the proximity of heat exposure to competition performance. Ultimately, it is not yet clear which strategy might be ideal for powerlifting (and strength and power performance more generally).

Therefore, the current study investigated the influence of PD as well as PD condition (i.e., AM vs. PM) on neuromuscular performance. Specifically, we chose the countermovement jump (CMJ), ballistic push-up (BPU), and isometric mid-thigh pull (IMTP) to provide information on the effect of PD on upper and lower body strength and power. These exercises were selected because they may relate to the spectrum of disciplines performed in powerlifting, being correlated with back squat [213], bench press [214] and deadlift performance [215], while also providing useful information to athletes in other sports. A comprehensive understanding of the effects of dehydration via heat exposure on these performance metrics will provide valuable insights for athletes and coaches to optimize their RWL strategy and timing.

Aims and Hypothesis

The aim of this study was to compare the impacts of PD and PD condition (AM vs. PM) on upper and lower body strength performance. Briefly, we compared PD the evening before strength testing (PD-PM), which induces a longer period of dehydration (including during sleep) but with heat exposure further from testing to PD performed the morning of testing (PD-AM), which induces a shorter period of dehydration, but with heat stress closer to strength testing. We hypothesised that PD would negatively impact strength and power performance, but that PD-PM would impact performance less than PD-AM due to the further proximity of heat stress to testing.

Section 2: Methods

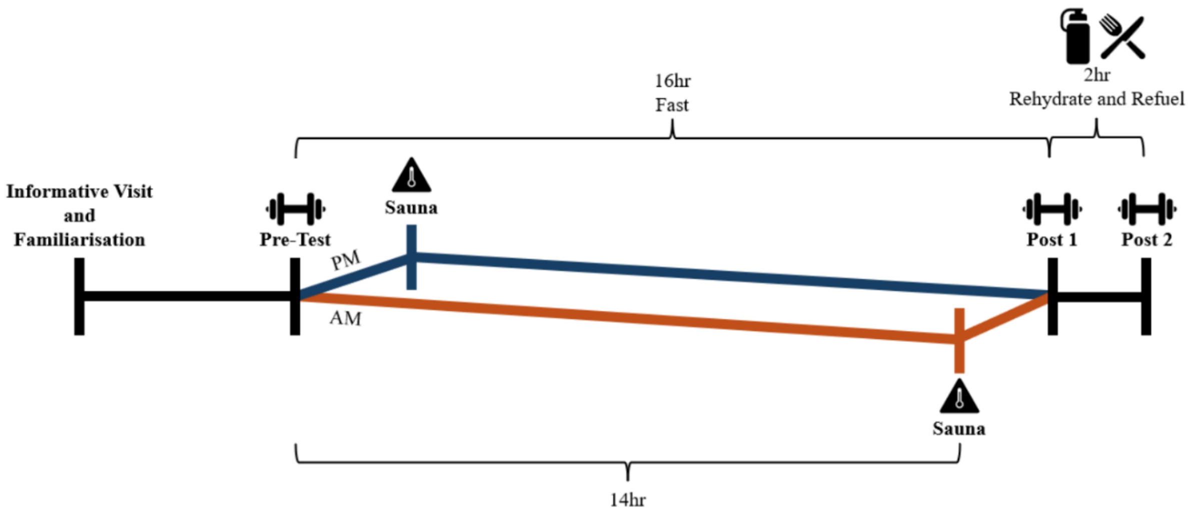
Participants

Participants were recruited through advertisements and word-of-mouth. 13 (8 males and 5 females mean age of 29.6±3.7 years and body weight 76.33 ±12.37kg) RT athletes (at least a 1.5x bodyweight squat and 1x bodyweight bench press and two years of training experience), volunteered for the study. The study procedures were thoroughly explained, and informed consent was obtained from each participant. This research was reviewed and approved by the University ethics committee, number 20/203.

Experimental Design

A single-group, repeated measures crossover design with a counterbalanced condition order was used. All participants performed a battery of tests (described below) across three testing sessions per condition, pre-test (PRE), post-test one (POST 1), post-test two (POST 2), and each participant performed both conditions, with a washout between conditions to prevent any carryover effects. Prior to beginning the study participants performed two familiarisation sessions 2 days between one another, in which they performed the same battery of tests that they would perform in the two conditions, twice per familiarisation session. After a minimum of 2 and maximum of 3 days after the second familiarisation session, participants were instructed to follow a standardised low CHO, LGV diet (see Chapter 5) for 3 days with macronutrient targets and a food list provided by the lead researcher, before assignment to the first condition. Participation was coordinated with each volunteer individually to sync the protocol with their planned deload training weeks (intentionally easy weeks scheduled for recovery) to minimise the influence of fatigue on the study, and to minimise the impact of the study on their personal training to enhancement recruitment and retention. After 3 days of following the standardised diet and after the second familiarisation session, participants were randomly counterbalanced with the first participant being assigned to either the PD-AM condition or PD-PM condition by performing a coin toss, and the next participant was assigned to the opposite condition. After each participant completed the first condition, they then completed the remaining condition after a three-week minimum washout period (Figure 6-1).

Figure 6-1 Study Design



During each condition, participants performed a strength testing battery three times (PRE, POST 1, and POST 2) making three maximal attempts for each performance test (CMJ, IMTP, BPU). During both conditions, participants performed the PRE at a similar time. Then, immediately after PRE, participants completed supervised PD in a lab-based sauna until 1.5% BM loss occurred at different time intervals prior to POST 1. POST 1 occurred either immediately after PD (PD-AM) or the following morning, after the participants slept and returned to the lab, 16 hours after the PRE (PD-

PM). After POST 1, in both conditions, participants were given two hours of rest, a standardised food and electrolyte solution, and access to ad-libitum water intake before performing POST 2, which was identical to the PRE and POST 1.

Test battery

1. Participants performed CMJs on a force plate (AMTI, ACP) with a dowel held horizontally across their shoulders to maintain upper body posture, mimic the position of a barbell back squat (for more relevance to strength sport) and to reduce arm swing. Participants began standing upright, and when the researcher provided a verbal cue, participants executed a downward motion by flexing at the hips, knees, and ankles while keeping the dowel stable and maintaining torso position. After reaching the point when thighs and hips are parallel, participants jumped by rapidly extending the hips, knees, and ankles. Participants performed three jumps with a minimum of one minute and a maximum of three minutes rest between attempts.

The force plate recorded force and time data at 1000HZ, and jump peak force was measured as the maximum force recorded from the force-time curve during the concentric phase of the CMJ. Maximum force for each attempt was determined using a custom script (MATLAB R2023b).

2. Participants performed BPU by assuming a standard push-up position with hands slightly wider than shoulder-width apart on the same force plate, feet together (females performed the BPU on knees), with the body in a straight line from head to heels. Participants were instructed to pause briefly at the bottom of the movement to eliminate any artificial force peaks, and then following a verbal cue explosively performed the BPU with the intention to make their arms leave the force plate and create flight time. Participants performed three push-ups with a minimum of one minute and a maximum of three minutes rest between attempts. The average force during the propulsive phase for each attempt were calculated from the force plate data using a custom script (MATLAB R2023b).

3. Participants performed the IMTP by standing on a plate with a chain connecting it to a stationary custom strain gauge (SPRINZ Laboratories, Auckland University of Technology),

connected to a handle held by the participants. Chain length was individually adjusted for each participant and held constant between testing sessions to standardize body position, with feet at shoulder width and the handle placed at mid-thigh, producing a knee angle between 125-135 degrees. Participants were given lifting straps to secure their grip and were instructed to pull as hard and fast as possible for three attempts, with a one minute minimum and a three-minute maximum rest interval between attempts. Participants were verbally motivated during the pull and were told to stop once peak force visually plateaued on the computer display. The highest peak force achieved during the three attempts was used for analysis.

PD protocol

The participant's BM was measured prior to entering a sauna (Smartmak, CE, ROHS, ETL, ISO9000) that was heated to 60 °C. Participants sat in the sauna and were monitored by the researcher to ensure symptoms of heat related illness did not occur. A heat stress questionnaire [216] as well as core temperature measurements were used to ensure safety. Core temperature was measured using a rectal thermometer (Hinco Instruments, Australia) self-inserted in a private room by participants to ~12 cm depth beyond the anal sphincter. Core temperature was monitored to ensure it did not exceed 40 °C. Following 20 minutes in the sauna, participants were given a 5-minute rest period to dry themselves off followed by measuring their BM (Tanita HD-366). Participants repeated this process until 1.5% of BM was lost.

Refuelling and rehydration protocol

During the two-hour rest period between POST 1 and POST 2, a standardised refuelling and rehydration protocol was implemented in which participants were instructed to consume a CHO electrolyte solution (Powerade, Mountain Blast) consisting of 28 g of CHO, 272 mg of sodium and 136 mg of potassium dissolved in 1000 ml of water and two snack bars (LCM Bar, Unicorn) consisting of 15.8 grams of CHO, 0.6 grams of protein and 1.7 grams of fat per bar. Participants were also instructed to consume ad-libitum water during the rest period.

Statistical analysis

Statistical analyses were performed using the R language and environment for statistical computing [217]. Specifically, the *tidyverse* environment for data condition, the *lmerTest* package for models, *ggeffects* to estimate marginal means, and the *easystats* framework (e.g., *performance*, *parameters*, and *effect size*) were implemented.

Descriptive statistics are presented as means with 95% confidence intervals (95% CI) for each dependent variable at each timepoint (PRE, POST 1, POST 2) within each condition (PD-AM, PD-PM). To address the primary aim—examining the effects of PD timing and timepoint on CMJ peak force, BPU mean force, and IMTP peak force—separate LMMs were constructed for each outcome. Each model included condition (AM vs PM), time (PRE, POST 1, POST 2), sequence (AM-first vs PM-first), and the condition × time interaction as fixed effects. Participant ID was included as a random intercept to account for within-subject repeated measures. Models were estimated using restricted maximum likelihood (REML) with the nloptwrap optimiser.

To avoid reliance on an arbitrary reference group, fixed effects were parameterised using sum-to-zero (effect) coding. Under this coding scheme, coefficients represent deviations from the grand mean (e.g., the condition coefficient reflects half of the AM–PM difference), which can make individual coefficients less intuitive to interpret in isolation. Therefore, inference focused primarily on (i) Type III tests for overall fixed effects and (ii) EMMs with pairwise contrasts, which provide the AM–PM differences directly at each timepoint and quantify within-condition changes over time. Follow-up analyses were conducted using EMM-based pairwise comparisons to examine (i) AM vs PM differences at each timepoint and (ii) within-condition changes over time (PRE vs POST 1, PRE vs POST 2, and POST 1 vs POST 2). Pairwise comparisons are reported as mean differences in raw units with 95% CIs and associated p-values. Between-condition differences were additionally quantified using Cohen's d effect sizes.

Analyses were performed on trial-averaged data (i.e., outcomes were averaged across trials within each participant and timepoint). This approach improved model diagnostics, and practical conclusions were consistent with analyses performed using trial-level data.

Model assumptions were evaluated using residual and diagnostic plots. Where potential violations were observed—primarily relating to residual normality and heteroscedasticity—results were compared against robustified mixed-effects models and bootstrap-based estimates. Fixed-effect inferences and conclusions were stable across approaches; therefore, standard LMM outputs are presented. Differences between CMJ, BPU, and IMTP values between conditions were quantified using Cohen's d effect sizes and were interpreted as follows: $d = 0.2$ was considered a small effect, $d = 0.5$ a medium effect, and $d = 0.8$ a large effect. Values below 0.2 were considered negligible, while those exceeding 1.2 were interpreted as very large [218].

Section 3: Results

CMJ (Peak Force)

There was no significant main effect of condition (AM vs. PM), on CMJ peak force (Estimate = −14.85, 95% CI: [−34.15, 4.45], $p = 0.119$). Time had a significant linear effect on CMJ performance, with values decreasing over time (Estimate = −36.30, 95% CI: [−59.94, −12.66], $p = 0.003$). However, the quadratic time term was not significant (Estimate = 20.74, 95% CI: [−2.87, 44.46], $p = 0.084$), suggesting that the decline over time was primarily linear. Participants who received the AM sequence exhibited significantly lower CMJ values overall (Estimate = -245.57, 95% CI: [-463.75, -27.38, $p = 0.031$), indicating a potential sequence or order effect. There were no significant interactions between condition and time, either for the linear term (Estimate = 17.66, 95% CI: -5.98, 41.30], $p = 0.140$) or the quadratic term (Estimate = −9.11, 95% CI: -32.71, 14.4], $p = 0.441$), suggesting that the rate of change in CMJ performance over time did not differ between conditions.

Estimated marginal means showed a small baseline difference favouring PM at PRE only (AM − PM = −62.1, 95% CI [−113.6, −10.6], $p = 0.019$, $d = -0.17$), whereas no AM–PM differences were observed at POST 1 or POST 2 (all $p > 0.50$). Within-condition contrasts indicated significant declines from PRE to POST 1 (74.72, 95% CI [16.5, 133.0], $p = 0.005$, $d = 0.20$) and from PRE to POST 2 (76.31, 95% CI [19.5, 133.1], $p = 0.005$, $d = 0.21$) in the PM condition, with no difference between POST 1 and POST 2 ($p = 0.946$). However, because the condition × time interaction terms were not significant, these within-condition support a differential performance decline between AM and PM.

BPU (Mean force)

There was no significant main effect of condition (AM vs. PM) on BPU performance (Estimate = −5.13, 95% CI [−17.06, 6.81], p = 0.408). Time had a significant linear effect on BPU performance, with values decreasing over time (Estimate = −11.75, 95% CI [−17.40, −6.09], p < 0.001). In addition, the quadratic time term was significant (Estimate = 14.36, 95% CI [8.76, 19.96], p < 0.001), indicating a non-linear time-course characterised by an initial decline with partial stabilisation thereafter. Participants who received the AM-first sequence exhibited significantly lower BPU values overall (Estimate = −121.65, 95% CI [−228.11, −15.18], p = 0.043), consistent with a sequence effect. There were no significant condition and time interactions for either the linear (Estimate = −3.05, 95% CI [−8.71, 2.60], p = 0.287) or quadratic term (Estimate = −0.35, 95% CI [−5.95, 5.24], p = 0.900), indicating that the time-course of BPU change did not differ between conditions.

Estimated marginal means showed no significant AM–PM differences at any timepoint (all $p > 0.26$), with trivial effect sizes (d range: −0.08 to −0.03). Within-condition contrasts indicated a significant decline from PRE to POST 1 in both AM (Δ27.62, 95% CI [13.76, 41.47], $p < 0.0001$; $d = 0.142$) and PM (24.17, 95% CI [10.31, 38.02], $p = 0.0002$; $d = 0.124$). In AM, values remained lower at POST 2 relative to PRE (20.93, 95% CI [6.66, 35.20], $p = 0.0014$; $d = 0.108$), whereas the PRE–POST 2 contrast in PM did not reach significance (12.29, 95% CI [−1.56, 26.15], $p = 0.065$; $d = 0.063$). No meaningful change was observed between POST 1 and POST 2 in either condition (AM: $p = 0.251$; PM: $p = 0.065$). However, condition and time interaction terms were not significant and do not support a differential performance decline between AM and PM.

IMTP (Peak force)

There was no significant main effect of condition (AM vs. PM) on IMTP peak force (Estimate = 13.88, 95% CI [−36.40, 64.17], $p = 0.556$). Time had both significant linear effect (Estimate = −129.95, 95% CI [−170.98, −88.61], $p < 0.001$) and a significant quadratic effect (Estimate = 97.92, 95% CI [57.27, 138.56], $p < 0.001$), indicating a non-linear pattern characterised by an initial decline with partial recovery/stabilisation thereafter. The sequence effect did not reach statistical significance (Estimate = −296.88, 95% CI [−638.09, 44.34], $p = 0.082$). There was no significant condition and time interactions for either the linear (Estimate = −22.03, 95% CI [−63.37, 19.31], $p = 0.289$) or quadratic terms (Estimate = −2.20, 95% CI [−43.16, 38.76], $p = 0.914$), indicating that the time-course of IMTP change did not differ between conditions.

Estimated marginal means showed no significant AM–PM differences at PRE (estimate = 57.12, 95% CI [−59.2, 173], $p = 0.321$; $d = 0.094$), POST 1 (estimate = 31.36, 95% CI [−84.9, 148], $p = 0.583$; $d = 0.052$), or POST 2 (estimate = −5.18, 95% CI [−122.9, 113], $p = 0.929$; $d = −0.009$), indicating minimal between-condition differences across time. Within-condition contrasts demonstrated significant reductions from PRE to POST 1 and PRE to POST 2 in both conditions. In AM, PRE exceeded POST 1 (estimate = 224.69, 95% CI [124.1, 325.3], $p < 0.0001$; $d = 0.369$) and POST 2 (estimate = 214.93, 95% CI [114.3, 315.6], $p < 0.0001$; $d = 0.353$), with no significant difference between POST 1 and POST 2 (estimate = −9.76, 95% CI [−110.4, 90.9], $p = 0.811$; $d = −0.016$). Similarly, in PM, PRE exceeded POST (estimate = 198.93, 95% CI [98.3, 299.6], $p < 0.0001$; $d =$

0.327) and POST 2 (estimate = 152.62, 95% CI [49.2, 256.1], $p = 0.0013$; $d = 0.251$), while POST 1 and POST 2 did not significantly differ (estimate = −46.30, 95% CI [−149.8, 57.1], $p = 0.272$; $d = -0.076$). However, as the condition and time interaction terms were not significant, these changes do not support a differential performance decline between AM and PM

Table 6-1 Results of PD on CMJ, BPU and IMTP.

		Estimated marginal means														
		Within-condition (AM-PM) contrast (Mean, 95% CI, Effect Size)			Cond		Time Linear		Time quadratic		Sequence		Cond x time [linear]		Cond x time [quadratic]	
Metric	Cond.	Post 1-PRE	Post 2-PRE	Post 2 -Post 1	Coeff.	P	Coeff.	P	Coeff.	P	Coeff.	P	Coeff.	P	Coeff.	P
CMJ Peak force (N)	AM	27.43 [−29.3, 84.2], d=0.142	26.37 [−33.6, 86.3], d=0.108	−1.06 [−61.0, 58.9], d=−0.034	−14.85	0.119	−36.30	**0.003**	20.74	0.084	−245.57	**0.031**	17.66	0.140	−9.11	0.441
	PM	**74.72 [16.5, 133.0], d=0.124**	**76.31 [19.5, 133.1], d=0.063**	1.59 [−56.7, 59.8], d=−0.061												
BPU Mean Force (N)	AM	**27.62 [13.76, 41.47], d=0.142**	**20.93 [6.66, 35.20], d=0.108**	−6.69 [−20.96, 7.59], d=−0.034	−5.13	0.408	−11.75	**<0.001**	14.36	**<0.001**	−121.65	**0.043**	−3.05	0.287	−0.35	0.900
	PM	**24.17 [10.31, 38.02], d=0.124**	12.29 [−1.56, 26.15], d=0.063	−11.87 [−25.73, 1.98], d=−0.061												
IMTP Peak Force (N)	AM	**224.69 [124.1, 325.3], d=0.369**	**214.93 [114.3, 315.6], d=0.353**	−9.76 [−110.4, 90.9], d=−0.016	13.88	0.556	−129.95	**<0.001**	97.92	**<0.001**	−296.88	0.082	−22.03	0.289	−2.20	0.914
	PM	**198.93 [98.3, 299.6], d=0.327**	**152.62 [49.2, 256.1], d=0.251**	−46.30 [−149.8, 57.1], d=−0.076												

N = Newtons, s = seconds, Cond. = Condition, Bold denotes a significant effect, d= Effect size

Section 4: Discussion

Our primary aim was to investigate the effects of PD performed in different conditions (PD-AM vs PD-PM) on subsequent strength and power performance, specifically CMJ force, BPU Force, and IMTP force. These tests were chosen specifically because they strongly correlate with 1RM back squat [219], bench press [220] and deadlift [215], the lifts contested in powerlifting. Further, requiring a participant to perform three 1RM strength tests in less than 24 hours would not have been practical, making these tests more logistically feasible than actual 1RM tests, while still providing actionable information. Our results indicate that the main effect of PD timing did not significantly impact any of the three strength tests. There were no significant condition interactions, disconfirming our hypothesis that the PM condition would experience a less significant performance decline compared to the AM condition. PD was associated with a sustained reduction in CMJ peak force at the later timepoints, most clearly in the PM condition. This suggests that even following the recovery period (rehydration and refuelling), CMJ performance may not fully return to baseline after PD, whether PD occurred 14-hours prior (PM) or immediately prior (AM), although condition and time interactions were not significant. Similar effects have been seen in combat athletes that continue to experience reduced performance 24-hours post dehydration. However, this contrasts a study on bench press 1RM, which found that reductions in performance were eliminated by two hours of rest and rehydration [30]. While surprising, this could be potentially explained by the differences in upper compared to lower body tasks, with the latter being more sensitive to dehydration-related fatigue. Notably, Jones and colleagues found that dehydration had a greater impact on lower body anaerobic power compared to the upper body [221].

In addition to the overall significant effect of time on CMJ, within-condition pairwise comparisons revealed statistically significant differences in the PM condition. Specifically, CMJ peak force was significantly lower at POST 1 relative to PRE and remained reduced at POST 2 compared with PRE. In contrast, no statistically significant differences were observed across timepoints in the AM condition. Importantly, comparisons between POST 1 and POST 2 were not significant in either condition, with no significant deterioration thereafter. Although the overall time effect indicates a reduction in CMJ performance following PD, the absence of a significant condition and time interaction shows there was no significant difference between AM and PM sessions.

The overall significant decline observed in the PM group for CMJ peak force across time is consistent with other studies examining dehydration and exercise performance [46, 222]; however, the lack of any POST 1 to POST 2 difference suggests that CMJ performance did not continue to worsen during the recovery period and instead stabilised following the initial decrement. Additionally, a significant sequence effect was observed, with participants who completed the AM-first sequence demonstrating lower CMJ peak force overall. This indicates a potential order or carryover influence on lower body performance outcomes and should be considered when interpreting between-condition comparisons.

A significant effect of time was observed for BPU mean force which corroborates previous research demonstrating that dehydration can negatively impact upper body strength and power, albeit temporarily [46]. Schoffstall and colleagues found that immediately after dehydration a reduction in bench press 1RM occurred, but performance restored 2-hours post rehydration [30]. This is partially seen in our finding with a significant effect observed in quadratic term indicating partial stabilisation post 2-hours post rehydration. In the present study, while overall time effects were evident, estimated marginal means showed no significant differences between AM and PM at any timepoint, regardless of whether PD was performed the night prior or immediately prior to testing. Within-condition contrasts showed small reductions from PRE to POST 1 in both conditions, with AM also remaining lower at POST 2, whereas the PRE to POST 2 and POST 1 to POST 2 comparisons in PM had low p values, but did not reach statistical significance. Collectively, these findings suggest that PD may induce modest short-term reductions in BPU mean force, but that recovery within a two-hour refuelling and rehydration window may be sufficient to limit further deterioration, and the timing of PD (PM vs AM) does not appear to meaningfully alter the performance. However, a significant sequence effect was observed, with participants completing the AM-first sequence demonstrating lower BPU mean force overall. This mirrors the sequence influence observed for CMJ and suggests that order or carryover effects may influence neuromuscular outcomes in crossover designs. Although the mechanism is unclear, this finding reinforces the importance of accounting for condition order in interpretation and warrants further investigation to determine whether this represents a true physiological carryover or simply a testing/order effect.

In the IMTP, a significant linear and quadratic decline of peak force was observed across time with most of the reduction occurring between PRE and POST 1 and between PRE and POST 2 in both conditions. However, the significant quadratic term suggests that the initial decline attenuated thereafter, consistent with partial stabilisation or recovery over time. This finding is supported by the pairwise comparisons, which indicated significant reductions from PRE to both POST 1 and POST 2 in AM and PM, while no significant changes were observed between POST 1 and POST 2 within either condition. Therefore, these results suggest that the primary performance decrement occurred early, followed by a period of stabilisation. Nevertheless, IMTP performance remained below baseline at the later timepoint, indicating that the rehydration and refuelling period was not sufficient for IMTP force to return to baseline. Interestingly, unlike the CMJ and BPU, the IMTP did not show a significant effect of sequence. This might suggest that sequence effects were influenced by proximity to dehydration. CMJ and BPU were performed earlier in the protocol and therefore closer to the acute stressor, whereas IMTP was assessed later after additional time for rehydration, refuelling, and psychological settling. This timing may matter disproportionately for explosive or dynamic measures (such as CMJ and BPU), which are typically more sensitive to acute fatigue, discomfort, and fluctuations in arousal than maximal isometric peak force [223, 224]. In this context, sequence effects may be more readily expressed in CMJ and BPU than in IMTP. This could indicate that a PD-PM session might serve to “acclimate” a participant to a subsequent PD-AM session, resulting in a less exaggerated second reduction in the performance of an exercise that occurred closer to the proximity of dehydration.

While this might be speculative, the concept of psychological priming might be taking place. Due to the nature of the condition, the PM group would begin PD in the evening after a day of drinking and eating, which could make the initial PD session subjectively easier compared to the AM condition in which PD occurred immediately upon waking in a fasted state. This speculation aligns with our anecdotal observations, as most participants reported that the PM condition felt easier compared to the AM condition. Psychological priming is the phenomenon in which positive mental imagery preceding a task leads to better outcomes compared in the actual task when compared to performing the task with no positive imagery, and even worse task performance when the task is preceded by negative imagery [225]. In general support of the concept of acclimation, Barley and colleagues reported that acclimation to heat exposure across repeated bouts improves mood after dehydration [226], which when combined with an initially more positive experience in PD-PM, could explain the observed effect of sequence. However, our study differed in design from Barley, as it included washout period of >3 weeks, which should have prevented physiological adaptation, making the likelihood of a psychological priming phenomenon a more likely mechanism. However, caution is warranted when considering this explanation, as we did not quantitatively measure the participants' affect, discomfort, or perceived exertion in either condition. Thus, future investigation is needed to test this hypothesis and ideally with a larger sample size.

Collectively, and in alignment with prior research, our primary findings suggest that performance decrements resulting from dehydration may manifest differently depending on the type and duration of tests [221]. Across test outcomes, PD was associated with clear time-related declines in IMTP peak force, and BPU mean and CMJ peak force declines were observed in the PM session. However, despite these time-related decrements, no condition and time interactions were identified across any outcome, indicating that whether PD was performed the night prior or immediately prior to testing had no differential impact on performance. However, and to conclude, sequence effects were also evident, with participants completing the AM-first sequence demonstrating lower overall CMJ and BPU performance. This indicates that order influences may meaningfully affect dynamic performance measures and should be considered when interpreting PD-related performance changes. One plausible explanation is that these order effects were amplified by proximity to dehydration, as CMJ and BPU were performed earlier in the testing battery and therefore closer to PD. In addition, psychological priming may have contributed, whereby the perceived difficulty of the initial session shaped expectations, arousal, and tolerance in the subsequent condition. Importantly, any priming-related influence may be expressed more clearly in sensitive performance qualities such as explosive or dynamic force production (e.g., CMJ and BPU), which are more vulnerable to acute fatigue, discomfort, and shifts in arousal than maximal isometric peak force (IMTP).

Lastly, it is also possible that overall strength and power performance was still in the process of recovering during testing. Only BPU and IMTP demonstrated significant quadratic time effects, indicating partial stabilisation of performance over the testing period. This pattern may reflect the influence of rehydration and refuelling, as a greater amount of recovery time had elapsed by the time these measures were assessed compared with CMJ, which was performed earlier and did not show any partial stabilisation. This pattern may indicate that rehydration post-PD was sufficient to prevent a continued decline in performance, but insufficient to fully restore it in the time allotted, indicating a more prolonged recovery period is necessary for a full return to baseline performance, aligning with some prior research in combat athletes [14].

It's important to acknowledge the potential limitations of this study, the first being that participants were only given 60g of CHO and 272 mg of sodium and 136 mg of potassium during the 2-hour rehydration and refuelling period. This might have been insufficient considering that electrolyte losses during heat exposure increases substantially [227]. Further, we did not measure differences in sweat rates between individuals, and there is notable inter-individual variability in electrolyte losses from sweating, adding to the potential possibility that uneven rehydration could have occurred despite a standardised rehydration strategy and loss of BM [228]. In addition, while participants were allowed ad libitum fluids for 2 hours post dehydration, the volume and rate of fluid consumed was not tracked which may impact rehydration rates [219]. Lastly, a small sample size reduces the ability to detect subtle changes in some performance metrics requiring replication for a confident interpretation of our results. While acknowledging these limitations, this is the first study to evaluate the effect of heat-induced PD and its timing on WRSA-relevant performance. Further, we also employed a two-hour post rehydration and refuelling period to simulate weigh-in and competition timelines in weightlifting and powerlifting, increasing ecological validity and potential translation of our results to practice. Future research should attempt to use larger sample sizes, evaluate individual sweat rates and composition, and determine if individualising the amount of CHO, fluids, and electrolytes consumed based on these metrics can further attenuate decrements in performance to a greater degree in similar conditions.

Section 5: Practical Applications

In conclusion, PD via heat exposure equal to a 1.5% BM reduction with a two hour rehydration and refuelling period 1) had broadly similar impacts on performance regardless of timing, but 2) resulted in a linear decline in CMJ, BPU and IMTP but with partial stabilisation in BPU and IMTP with 3) the possibility that a 2-hour rehydration and refuelling protocol stops this performance decline but is insufficient to restore performance to baseline, and finally 4) one may be able to leverage the potential beneficial psychological adaptation of performing an easier bout of PD prior to a latter bout, based on our observed sequence effect. These findings provide novel insights into the complex interplay between hydration status, exercise performance, and the potential influence of psychological factors, particularly in the context of powerlifting, but warrant further research for confirmation.

Chapter 7 Conclusion, practical applications and future research.

Section 1: Discussion

The overall objective of this thesis was to investigate the multifaceted RWL strategies employed by WRSA, understand the impact of RWL on their physiological, psychological, and performance-related dimensions, and to provide more clarity to athletes and practitioners on best practice to minimise health and performance risks when employing RWL. The literature review (Chapter 2) focused primarily on first identifying the similarities and differences in RWL strategies used by combat athletes compared to strength athletes given the limited study of the latter group. While some inferences can be made, due to the differences in the metabolic demands, performance goals, and PWI periods between strength and combat sports, direct extrapolation is not always appropriate. Therefore, several studies were subsequently conducted to address the identified gaps in the existing literature, with the aim of informing RWL best practices for the WRSA.

To better understand the practices employed by WRSA, the first investigation (Chapter 3) explored the prevalence and patterns of RWL behaviours among powerlifters competing at the 2018 World Championships. Notably, 83% of powerlifters and 90% of medal winners engaged in RWL. Medallists lost more BM than non-medallists (4.1% vs 2.7%) and winning a medal was associated with the number competitions the athlete participated in that year, possibly indicating that a BM loss of ~2-4% could be considered normative, and that medallists either can practice or adapt to RWL. Our first investigation did not quantify the subjective wellbeing and psychological changes of those engaging RWL, but 19% of respondents reported a perceived decrease in performance. This investigation highlights the pervasive nature of RWL within powerlifting and its complex interaction with subjective wellbeing and performance, reinforcing the need to better understand the effects of RWL on these factors to inform best practice.

Therefore, the second study (Chapter 4) sought to explore the impact of RWL on subjective wellbeing and performance by evaluating changes in SRSS scores among powerlifters competing at the 2019 and 2022 World Championships. Interestingly, these powerlifters’ scores indicated that they managed subjective stress and recovered leading into competition, and that the higher the GLP of the powerlifter, the better they managed their negative emotional state. Additionally, the more weight that was lost, the worse the subjective stress and recovery scores were, with female powerlifters experiencing larger detriments to SRSS scores with higher magnitudes of weight loss. These findings align with Chapter 3, indicating that elite powerlifters learn to manage the stress of RWL with experience and exposure. However, at this stage of the thesis, conclusions remained speculative as no experimental work had yet been performed.

Building upon these findings, the third study (Chapter 5) described normative ranges of weight loss associated with a low-risk RWL, low CHO, LGV strategy, not requiring an energy deficit or dehydration. A repeated-measures crossover study was employed to investigate the BM loss effects of a practically applied LGV, the repeatability of this effect, and its acceptability among males and females. Across both trials, participants lost 1.4%-1.7% of BM following a 3-day LGV, not requiring caloric restriction or an onerous process of weighing, measuring, and controlling fibre intake. Worthy of future study, when an outlier who happened to have the highest baseline CHO intake was removed, a potential explanatory mechanism for the magnitude of BM loss became apparent. Specifically, the cumulative CHO deficit achieved by reducing CHO intake (by 60%) by making an isocaloric dietary fat exchange predicted BM losses. Importantly, in prior research, an LGV also produced weight loss, but of a lower magnitude, indicating that concomitant CHO restriction (but not necessarily to ketogenic levels) during an LGV can increase BM loss. Notably, 12 out of 13 participants indicated they would repeat a similar LGV in the future for competition. Therefore, this method can be employed by WRSA who need to lose approximately 1.4%-1.7% of BM without any expected loss of performance based on prior research and the method and explanatory mechanism of weight loss.

The final study (Chapter 6) sought to evaluate the impact of RWL via heat exposure resulting in a 1.5% loss of BM on strength performance in RT males and females. Heat-induced PD is a common strategy but also carries the most risk to health and performance given the combined effects of heat stress and dehydration. Thus, this final study sought to investigate how to minimise the negative impacts of this RWL strategy. Participants performed the CMJ, BTU, and IMTP, exercises related to the powerlifts but also with broader applicability, to assess the impact of heat-induced PD and its timing on their performance. Notably, the timing (AM or PM) of heat-induced PD did not influence its detrimental effects on performance. However, a decline in performance for all three exercises (CMJ, BPU and IMTP, was still observed even after 2 hours of rest and rehydration. Interestingly, the BPU and IMTP exhibited signs of a halt in performance decline in both the AM and PM conditions, suggesting more time or potentially more aggressive rehydration and refuelling strategies could further restore performance. Applying this finding to competition could indicate the initial competition attempts should be more conservative following RWL if it includes PD, as refuelling and rehydration may still be occurring, but latter attempts (and especially the bench press and deadlift) may be less likely to be affected. Additionally, the participants that performed PD in the PM first had lower drops in performance in their second PD session in the AM, hinting at a potential psychological adaptation. Therefore, an easy PD priming session could mitigate the negative future impact on performance following subsequent PD, acting as a positive psychological primer, although this remains speculative.

To conclude, RWL prevalence in powerlifters is widespread despite a lack of specific research on RWL in the WRSA. Elite powerlifters exhibit greater ability to manage the negative impact of RWL, which may lead to better competitive outcomes and the ability to maintain a higher bodyweight prior to competition. Maintaining a higher bodyweight may allow higher training loads, energy intakes, higher degrees of muscularity, and ultimately, greater strength. When the process of RWL is undertaken, individual differences are notable, with some trends observed based on sex and competitive calibre. Consistent with other research on combat athletes, female lifters tend to exhibit higher negative stress compared to males in response to RWL. However, both males and females can lose BM effectively (~1.5% of BM) without resorting to PD or energy restriction through the implementation of a practical 3-day LGV with concomitant, mild CHO restriction. Notably, mild PD (equal to an additional ~1.5% loss of BM) can be safely used as part of a well-planned RWL strategy to maximise competitive advantage. However, PD can lead to decline in lower body strength, but potential restoration could occur through individualised rehydration and refuelling, and possibly via positive psychological priming by performing an easier bout of PD in advance of competition. Considering the current body of evidence alongside our investigation, LGV should be employed before PD if preventing performance declines is of utmost importance.

Section 2: Limitations

Several limitations warrant consideration when interpreting the findings in this thesis. The survey sample size in Chapter 3 was modest, focusing primarily on elite powerlifters competing at the World Championships. This may limit generalisability to the broader population, especially those not planning to employ RWL strategies. Similarly, Chapter 4 involved elite powerlifters at the World Championships, and the use of a subjective wellbeing questionnaire, which may yield different findings from those competing locally. Additionally, specific RWL strategies were not evaluated, nor was travel distance accounted for, which could interact with powerlifters' reported subjective wellbeing. Finally, both surveys were conducted specifically at World *Classic* Championships; classic denotes the competitive category of powerlifting in which supportive equipment is limited to a belt, wrist wraps and knee sleeves, while *equipped* is the competitive category in which single-ply, supportive bench press shirts, squat suits and briefs, knee wraps, and deadlift suits can be worn. While the competitive rules in the IPF in both categories are identical with regards to the timing of weigh-ins, length of the post WIP before competing, and the specific weight classes, other factors could plausibly influence outcomes if these surveys had been conducted with equipped competitors. Specifically, the time and effort it takes to get in and out of equipment and the higher absolute loads which can be lifted may be differentially impacted by RWL. Thus, equipped powerlifters may report different magnitudes of BM loss, RWL methods, and there may be different relationships and interactions between BM losses, RWL practices, competitive level, subjective experiences, and performance.

The primary limitations of Chapters 5 and 6 were their small sample sizes. Larger samples could reduce random error and variation, potentially increasing statistical power. Chapter 5 employed a flexible approach to reducing fibre without specifying an amount, which may have contributed to greater inter-individual differences and increased variability. In Chapter 6, a larger sample could have mitigated the impact of individual differences in sweat rates and decreased uncertainty.

Despite these limitations, the findings from Chapters 5 and 6 can still inform the development of practical approaches for the WRSA to employ RWL strategies in preparation for competition.

Section 3: Practical Applications

Based on the findings of this thesis, the practical recommendations are as follows:

- Powerlifters do not necessarily need to use RWL strategies to perform well in competition. In fact, RWL carries a risk of performance decrement, with the degree varying depending on the magnitude, specific methods, and the lifter's experience and adaptations to performing RWL.
- Elite powerlifters (e.g., those experienced competitors who have a competitive necessity to make weight to place higher at championship events) may employ RWL strategies to gain a competitive advantage.
- When using RWL, start with a method that has a lower impact on performance.
- An LGV with modest CHO restriction is a tolerable and reliable way to induce a 1.4%-1.7% reduction in BM for both males and females.
- Mild BM loss via heat-induced PD can be done either in the AM or PM with no noticeable differences in how it impacts performance. This means considerations such as athlete preference and logistical availability can take precedence.
- Mild BM loss via heat-induced PD primarily impacts lower-body strength performance and may take more than two hours to recover from and therefore should be employed carefully. Opening squat (or snatch) attempts should be more conservative if PD is employed, with subsequent larger jumps on second and third attempts if recovery lags and requires more time.

- Performance and psychological decrements from PD may be further mitigated through individualised rehydration and refuelling strategies, as well as an easy acclimation PD session in advance of competition in which PD is planned.

Section 4: Recommendations for future research

- Chapter 2 synthesised research on RWL strategies used by combat athletes, and the results were extrapolated to the WRSA population after acknowledging similarities and differences. However, future reviews should focus specifically on the WRSA as more research is published, as there is a large gap in the literature for this specific population.
- Chapter 3 presented an in-person survey examining the RWL strategies employed by elite powerlifters. Future research could expand upon this by surveying a wider population of powerlifters (including equipped lifters) to improve the generalisability of the results, as well as including coaches, who are heavily involved in their athletes' competition preparation.
- Chapter 4 was an exploratory study investigating the subjective wellbeing of powerlifters using RWL and its association with performance at the World Classic Championships. While establishing a link between RWL and certain measures of subjective wellbeing, future research could delve deeper by examining the specific RWL strategies used by powerlifters, while also considering the impact of travel. Since this was an exploratory study, future research can build upon these findings by measuring specific outcomes. Further, like Chapter 3, different powerlifting demographic groups could be targeted to determine if there are differences based on equipment use, or age (i.e., replicating this research at Masters or Junior World Championships).
- Chapter 5 confirmed that a low-energy, high-fibre diet is effective in reducing BM in powerlifters. However, as this study did not prescribe a specific amount of fibre nor track fibre intake, future studies could either standardise the fibre intake during the

LGV diet or monitor it to assess whether the amount of fibre affects the magnitude of weight loss. Additionally, while hypothetically performance should not be impacted by BM losses induced via a LGV diet, no performance measures were taken. Future studies should include performance tests to assess this hypothesis.

- Chapter 6 demonstrated that performance decline in exercises replicating the squat, bench and deadlift occurs regardless of the timing heat-induced PD. Future research should explore alternative rehydration and refuelling strategies, as well as subjective wellness measures, to further develop potential strategies for the WRSA using PD.

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Appendix A AUT Ethics approval (Chapters 3 and 4)

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
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T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

8 May 2019

Eric Helms
Faculty of Health and Environmental Sciences

Dear Eric

Re: Ethics Application: **18/161 Assessment of readiness in Powerlifters preparing for competition**

Thank you for your request for approval of amendments to your ethics application.

The amendment to the application to include an additional phase related to readiness is approved.

I remind you of the **Standard Conditions of Approval**.

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. If the research is undertaken outside New Zealand, you need to meet all locality legal and ethical obligations and requirements.

For any enquiries please contact ethics@aut.ac.nz

Yours sincerely,

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

Cc: kedric93@gmail.com; John Cronin; Adam Storey

Appendix B AUT Ethics approval (Chapters 5 and 6)

25 November 2020
Eric Helms
Faculty of Health and Environmental Sciences

Dear Eric

Re Ethics Application: **20/203 The effect of acute heat exposure and dehydration on strength performance**

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

Your ethics application has been approved for three years until 17 November 2023.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: kekwan@aut.ac.nz; csousa2016@fau.edu; ivan.jukic@aut.ac.nz; alyssajoyspence@gmail.com

Appendix C Questionnaire from Chapter 4

Short Recovery Scale

Below you find a list of expressions that describe different aspects of your current state of recovery. Rate how you feel **right now** in relation to your best ever recovery state.

Physical Performance Capability

e.g.
strong,
physically capable,
energetic,
full of power

does not apply at all	0	1	2	3	4	5	6	fully applies
	○	○	○	○	○	○	○	

Mental Performance Capability

e.g.
attentive,
receptive,
concentrated,
mentally alert

does not apply at all	0	1	2	3	4	5	6	fully applies
	○	○	○	○	○	○	○	

Emotional Balance

e.g.
satisfied,
balanced,
in a good mood,
having everything under control
stable,
pleased

does not apply at all	0	1	2	3	4	5	6	fully applies
	○	○	○	○	○	○	○	

Overall Recovery

e.g.
recovered,
rested,
muscle relaxation,
physically relaxed

does not apply at all	0	1	2	3	4	5	6	fully applies
	○	○	○	○	○	○	○	

Short Stress Scale

Below you find a list of expressions that describe different aspects of your current state of stress. Rate how you feel **right now** in relation to your highest ever stress state.

Muscular Stress
e.g.
muscle exhaustion,
muscle fatigue,
muscle soreness,
muscle stiffness

does not apply at all	0	1	2	3	4	5	6	fully applies

Lack of Activation
e.g.
unmotivated,
sluggish,
unenthusiastic,
lacking energy

does not apply at all	0	1	2	3	4	5	6	fully applies

Negative Emotional State
e.g.
feeling down,
stressed,
annoyed,
short-tempered

does not apply at all	0	1	2	3	4	5	6	fully applies

Overall Stress
e.g.
tired,
worn-out,
overloaded,
physically exhausted

does not apply at all	0	1	2	3	4	5	6	fully applies

Appendix D Food list of: Common fibre rich food to avoid

Supp File 1: Common fibre rich food to avoid

1. All vegetables
2. All fruits
3. Potatoes
4. Sweet Potatoes
5. Beans
6. Lentils
7. Seeds
8. Wholewheat pasta
9. Wholewheat bread
10. Brown rice
11. Oats
12. Any form of whole grain cereal or muesli