Exploring “peaking” in physique sport: background, current practices, and evolving measurement techniques

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Abstract

Physique athletes are subjectively ranked against each other based on their on-stage presentation per the relevant judging criteria. Athletes attempt to display various, division-specific degrees of muscle size, definition, symmetry, and proportionality through posing. To do so, prolonged periods of energy restriction and resistance training (RT) are implemented during contest preparation. Nutrition and training are manipulated further in the final week before competition ("peak week" [PW]) to acutely enhance aesthetic performance. While many physique athletes implement peaking strategies, they are insufficiently detailed in the literature and their efficacy is unknown. Therefore, the purpose of this thesis was to determine the current nutrition and RT practices during PW across a broad range of competitors, provide directions for future research to evaluate these strategies, and offer practical applications for coaches and competitors who implement these strategies. Chapter 1 includes a background of peaking practices, thesis aims, and organisation. Chapter 2 critically examines and appraises the literature relating to carbohydrate (CHO) manipulation during PW, providing direction for future research and practical applications for coaches and competitors. Currently, there is a small but growing body of research related to peaking for physique sport; however, the only experimental design which sought to examine bodybuilding strategy is limited in its methodology. As well as providing broad practical applications, these findings lay the foundation for Chapters 3 and 4 with the objective of ascertaining a greater understanding of competitors' current peaking practices. Chapter 3 explores the PW nutrition strategies via a competitor survey and how these relate to competitor demographics. While CHO back loading was the most implemented strategy, no demographics predicted the choice of CHO-based strategies. Contrastingly, enhanced (performance enhancing drug [PED]-using) competitors were more likely to restrict water than natural, while males and professionals were more likely to load sodium in comparison to females and amateur competitors, respectively. Finally, males had a greater disparity between the lowest and highest daily CHO intakes during PW than females. The predictive relationship between demographics and PW RT manipulation was similarly explored via survey in Chapter 4. No relationships between competitor characteristics were found; however, competitors reduce training stress during PW by reducing set volume, loads, and proximity-to-failure. Repetition ranges increased for compound exercises while training split changes were prevalent, perhaps in synergy with nutritional PW strategies. Chapter 5 validated a portable ultrasound device, with the aim of facilitating future research participation via increased practicality. Specifically, the agreement between the portable Lumify and stationary Vivid S5 was evaluated for muscle thickness (MT). Across five measurement sites, the devices displayed practically perfect correlations, trivial differences and low systematic bias and random error, showing that the Lumify device is largely interchangeable with the Vivid S5 for MT measurements. Finally, Chapter 6 provides a general summary for the thesis, practical applications for coaches and competitors, and directions for future research. By furthering our understanding of physique sport peaking practices, this thesis provides valuable information enhancing the ecological validity of future research, thereby contributing towards informing the real-world practices of competitors.

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List of Abbreviations

AIC: Akaike information criterion

AAS: anabolic-androgenic steroids

BIA: bioelectrical impedance analysis

BIS: bioelectrical impedance spectroscopy

BM: body mass

CHO: carbohydrate

ΔBM: change in body mass during competition preparation

χ^2: chi-squared

R^2: coefficient of determination

CI: confidence interval

CSA: cross-sectional area

df: degrees of freedom

DW: dry weight

ES: effect size

ECW: extracellular water

GLUT: glucose transporter

GLUT5: glucose transporter five

GI: glycaemic index

ISAK: International Society for the Advancement of Kinanthropometry

ICW: intracellular water

ICC: intraclass correlation coefficient

LRT: likelihood ratio test

LoA: limits of agreement

LBC lower body compound

LBI lower body isolation

MRI: magnetic resonance imaging

MCA: multiple correspondence analysis

MT: muscle thickness

OR: odds ratio

PW: peak week

r: Pearson's product-moment correlation coefficient

PED: performance enhancing drug

τ: random effects

β: regression coefficient

RIR: repetitions in reserve

RT: resistance training

SGLT1: sodium-glucose cotransporter one

r^2: square of Pearson's product-moment correlation coefficient

SD: standard deviation

ST: subcutaneous tissue thickness

TBW: total body water

UBC: upper body compound

UBI upper body isolation

VIF: variance inflation factor

σ^2: variance of error

WBPW: week before peak week

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Appendix C *Questionnaire for Chapters 3 and 4*

The full questionnaire used to gather the data for Chapters 3 and 4 in this thesis can be found on the Open Science Framework using the following link: https://osf.io/a5czq.

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.

Signed:

Date: 23/10/2023

Co-authored Works

Manuscript under review

Homer KA, Cross MR, Helms ER. Peak Week Carbohydrate Manipulation Practices in Physique Athletes: A Narrative Review. Sports Medicine – Open.

Declaration of Collaboration

Chapters 2 to 5 of this thesis represent separate manuscripts that either will be or have been submitted to peer-reviewed scientific journals for publication. My contribution and the contributions of the various co-authors to each of the manuscripts are outlined below. All co-authors have approved the inclusion of the joint work in this thesis.

Chapter 2: Homer KA, Cross MR, Helms ER. Peak Week Carbohydrate Manipulation Practices in Physique Athletes: A Narrative Review. *Sports Medicine – Open* (under review).

KAH 80%, MRC 7.5%, ERH 12.5%

Chapter 3: Homer KA, Cross MR, Helms ER. An Examination of the Associations Between Nutritional Peaking Strategies in Physique Sport and Competitor Characteristics. In preparation for submission to the *Journal of the International Society of Sports Nutrition.*

KAH 85%, MRC 7.5%, ERH 7.5%

Chapter 4: Homer KA, Cross MR, Helms ER. A Survey of Resistance Training Practices Among Physique Competitors During Peak Week. In preparation for submission to *The Journal of Strength & Conditioning Research.*

KAH 85%, MRC 7.5%, ERH 7.5%

Chapter 5: Homer KA, Cross MR, Helms ER, Jukic I. The Concurrent Validity of a Portable Ultrasound Probe for Muscle Thickness Measurements. In preparation for submission to *The Journal of Strength & Conditioning Research.*

KAH 85%, MRC 3.5%, ERH 1%, IJ 10.5%

We, the undersigned, hereby agree to the percentages of participation in the chapters identified on the previous page:

Supervisors' signatures (primary, secondary)

Dr. Eric Helms

Dr. Matthew Cross

Co-author's signature

Dr. Ivan Jukic

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Ethics Approval

Ethics approval for the research conducted for Chapters 3 and 4 was granted by the Auckland University of Technology on the 18th of August 2022 for a period of three years (AUTEC reference number 22/208). Ethical approval for the research conducted for Chapter 5 was covered under the application 20/282 and its associated amendments.

Chapter 1: Introduction

1.1. Background and Rationale for this Research

Competitive bodybuilding has emerged and evolved over the last century, eventually coalescing into the present form of modern physique sport that encompasses multiple competitive divisions for men and women. Physique sport athletes are subjectively judged and ranked per the relevant criteria of the competitive division based on their on-stage presentation [1]. Generally, athletes across different divisions are judged on a combination of muscle size, symmetry, proportionality, and low body fat (muscle definition) presented through posing [2]. Accordingly, high-performing competitors maximise these variables, typically after years of progressive RT, by implementing appropriate pre-competition nutrition and training regimens once they begin their competition preparation phase following the off-season. In preparation for competition, athletes typically restrict energy intake and employ high volumes of RT for a prolonged period, which is often at least four months as seen in recent case studies of physique competitors [1, 3, 4].

The final week before competition is colloquially known as PW and involves further manipulation of nutrition and training to acutely enhance the size and appearance of muscle by increasing muscle glycogen content while minimising subcutaneous tissue thickness (ST) and abdominal bloating [2, 4]. Nutritional PW strategies are typically centred around the manipulation of CHO while training adjustments to maximise the efficacy of these strategies have also been observed [5].

Some of these strategies are likely adopted from the practices of endurance athletes who look to improve aerobic performance by maximising glycogen stores. Glycogen is the storage form of CHO for which skeletal muscle and liver are the largest stores, and is the primary substrate metabolised to provide energy and maintain blood glucose levels during intense exercise [6]. Thus, the first CHO loading protocols were conducted in endurance athletes, where glycogen depletion followed by CHO loading resulted in the supercompensation of muscle glycogen [7–13]. Typically, within these protocols, glycogen depleting exercise with the restriction of dietary CHO is followed by tapering and a predominantly CHO-based diet [14]. As an area of extensive research, further experimentation with large CHO loads scaled to bodyweight have resulted in considerable muscle glycogen increases [15, 16], leading to increased muscle cross-sectional area (CSA) as observed in one study [17].

While findings from studies using endurance athletes are understandably of interest to physique competitors, the direct implementation of such protocols may not be appropriate for maximising on-stage presentation. As an important distinction between the athletes, endurance athletes are not concerned with the aesthetic effects of CHO loading. However, relevant for physique athletes, loading with too much CHO has been proposed to obscure muscle definition through the accumulation of glucose and water in the subcutaneous layer [4]. Additionally, the physiology of physique athletes during PW would differ from endurance athletes, where very low body fat following months of energy restriction during competition preparation may lead to differing rates of glycogenesis. These differences highlight the need for further research on CHO loading protocols in the context of physique athletes, which is currently limited.

While there are several case and observational studies examining the peaking strategies of competitors, the only experimental trial was conducted by Balon et al. [18], who intended to replicate a CHO loading protocol implemented by physique athletes. While no significant increases in girth measurements were found following the protocol [18], the lack of methodological replication of PW conditions of athletes limit the generalisability of the results. Unfortunately, the participants recruited for this study had much higher body fat than that of physique athletes in PW without having dieted or reduced CHO intake before the study. This is an important consideration as chronic glycogen depletion from contest preparation could affect the rate of glycogenesis. Additionally, the participants consumed an isoenergetic diet throughout both depletion and loading, which does not replicate the practices of physique athletes in PW and may not have been sufficient to maximise glycogen storage [19, 20]. Further, the RT protocol implemented during depletion was likely much higher in intensity and volume than what is practiced by natural bodybuilders [21], who have been observed to decrease training stress during PW [22–24]. The high set volume and intensity during CHO restriction may have resulted in excessive muscle damage and sarcolemmal membrane disruption, potentially diminishing glycogenesis in the subsequent CHO load [25–29]. Finally, while girths did not increase significantly, granular increases in muscle size and/or a visual change in the appearance of muscle may not have been captured.

The limitations present within the experimental trial by Balon et al. [18] and the overall physique sport literature indicate the need for further research on peaking. Specifically, research designs with greater ecological validity are required to better guide the practices of coaches and competitors. A first step to developing such studies is elucidating the current practices of competitors. Currently, only a survey [30] and subjective interviews of high level competitors [24], both of which captured a highly homogenous sample (limiting the generalisability of the findings), are available to inform future designs. Further, a greater understanding of how competitor characteristics predict the implementation of different strategies would provide a more global understanding of the current peaking practices of competitors.

A small but growing body of physique sport peaking research attests to the interest, yet challenge in recruiting for and conducting such studies. For example, in an observational study by Nunes et al. [31] which took place ~24 hours before a competition, only 11 of 50 approached competitors participated. This study was conducted at the venue of competition (and not in a laboratory) and was purely observational. However, the researchers struggling to attain a reasonable sample evidence the past and ongoing difficulty of recruiting physique sport athletes for experimental research. To maximise the potential for participant recruitment, researchers may need to travel to locations which hold a larger proportion of physique athletes (i.e., either to a competition or to another city/country). However, to conduct research in the field, valid and reliable portable research instruments which capture the variables of interest are required.

MT and ST are outcomes that can be captured by ultrasound and are often reported in the physique sport literature. As peaking protocols may only result in transient changes in physique, accurate and precise instruments are needed (e.g., ultrasound) to capture granular changes. For example, in an examination of three RT studies that captured both ultrasound MT and girth measurements, change in the variables were correlated; however, ultrasound measurements were more sensitive to smaller changes [32]. Such results highlight the importance of using research instruments like ultrasound in the context of physique athletes. However, laboratory-grade ultrasound devices are relatively expensive, constrained by their transportability, and are dependent on the availability of practitioners who are trained and experienced in collecting such measurements, potentially affecting their utility in the field.

Fortunately, portable ultrasound probes which only require a tablet or phone to scan have become more readily available. Such devices, for example the Philips Lumify (Philips Healthcare, Amsterdam, Netherlands), pose a cheaper and more transportable alternative to conventional, stationary devices; however, to ensure that these devices provide valid measurements, their agreement with high-end devices needs to be evaluated. Currently, the validity of the Lumify has only been evaluated in measuring muscle architecture of the lower limb [33]. Further research is required to ensure that MT measurements using the Lumify at sites that are practically relevant and of interest to physique athletes (i.e., both upper and lower body) are valid before its use in such research.

While the use of peaking strategies amongst physique athletes are common [30], there is very little evidence behind these practices. Currently, there is only one experimental trial with many limitations and few case and observational studies which have examined such practices. Additionally, only two cross-sectional studies have captured the peaking practices of competitors within relatively small and homogenous samples [30, 34]. With the potential for building upon the knowledge gap regarding the nutritional and RT practices during PW, further cross-sectional information is required to guide the development of ecologically valid research designs.

Given the potential difficulty in participant recruitment, the validation of portable research instruments like the Lumify is also required to capture important outcome variables and maximise participants. By increasing the sample size within designs with high degrees of ecological validity, results from future research can hold greater statistical power and generalisability which will help guide the practices of coaches and competitors.

1.2. Purpose of this Research

The overall purpose of this thesis was to better understand nutritional and RT strategies around peaking and means via which important outcomes might be measured. This can be separated into several areas of foci which form the basis of the thesis aims. The first was to critically appraise the research related to peaking and to determine the peaking practices of physique competitors captured in the literature. In this manner, further insight into the area would be garnered to help guide the development of impactful experimental research designs. Secondly, to complement the literature review, a survey on the specific PW practices of modern athletes were undertaken to ensure the most up to date practices of physique athletes were established. Thirdly, to improve the access to participants within this area of research, there is a need for the validity of portable research instruments, such as the Lumify, to be evaluated. Thus, the level of agreement between the Lumify and GE Vivid S5 (General Electric Company, Boston, USA) was assessed to determine the utility of the Philips Lumify in collecting MT measurements for future research in the area. In addition to identifying gaps in the scientific literature and ascertaining information to develop more ecologically valid designs, research from this thesis was intended to inform coaches and competitors who plan to or are already implementing peaking strategies.

Therefore, the specific aims of this thesis were to:

1. Critically examine and appraise the existing literature relating to CHO manipulation during PW.
2. Investigate the nutritional and RT strategies implemented by competitors and whether the implementation of such strategies is influenced by competitor characteristics.
3. Validate a portable ultrasound device (Lumify) in the collection of MT measurements for use in future research within this area.

1.3. Significance of this Research

Currently, the recommendations published in the scientific literature are largely based on speculative physiological mechanisms and anecdotal experiences. For example, it has been proposed that within a traditional CHO backload (loading at the end of the week immediately preceding competition), three days of low CHO (0.5-1.5 g/kg BM) should be followed by two days of loading (4-12 g/kg BM) and one day of tapered intake (1-3 g/kg BM) [2]. While these recommendations account for the lack of evidence and the need for individualisation for strategies (indicated by the broad ranges provided), such an approach has not yet been tested. Likewise, general recommendations for RT changes have been made to enhance nutritional PW strategies [2]; however, there is no empirical information on the current RT practices of competitors during PW. Finally, the manipulation of fluid and electrolyte intake is speculated to enhance the appearance of muscle through blood pressure and body fluid distribution changes [2, 4], but has also not been studied.

While such recommendations seem physiologically plausible, the efficacy of these strategies needs to be tested under scientifically rigorous and ecologically valid conditions. As a general heuristic, future designs should only recruit individuals in conditions alike physique competitors during PW and implement appropriate nutritional and RT protocols used in practice. As these practices likely vary across competitors, characteristics such as sex and division need to be accounted for when considering the protocol being tested. For example, men's physique division competitors do not require the same extreme muscularity or leanness as bodybuilding, thus, their peaking protocols may not be appropriate for one another. An examination of competitor characteristics and how they predict the peaking strategies implemented would allow for a more global understanding of the current practices to guide future research.

To maximise numbers of population-relevant participants and statistical power of peaking studies, it may be necessary for researchers to travel to locations with a larger population of competitors and competitions. Doing so requires new, more affordable, portable research instruments like the Lumify portable ultrasound probe to be validated against a "gold-standard" criterion. Validation is not only an important step towards maximising participation but would also help practitioners conduct valid field-based assessments not limited to physique athletes.

To summarise, there is substantial theoretical and practical importance in thoroughly examining the existing literature regarding peaking in physique sports as well as identifying and expanding upon the present limitations. Further, to develop robust study designs with ecological validity, a greater understanding of the current practices of competitors and the validation of facilitative technology to study them is also required. Thus, the present thesis identifies important gaps in the literature and provides direction and tools for future research in addition to furthering the understanding of the current practices of competitors. The findings from this thesis will have direct practical implication for coaches and competitors who look to implement PW protocols and for researchers looking to conduct further research in this area.

1.4. Thesis Organisation

This thesis follows AUT's Manuscript Format 2, where Chapters 2 to 5 (i.e., excluding the introduction and discussion) were written in the format required for submission to peer-reviewed, journal articles which are in different stages of publication.

Chapter 2 is a narrative review of the scientific literature relating to PW CHO manipulation practices of physique athletes which is currently in the second stage of revision at *Sports Medicine – Open*. This review is the first to critically appraise in detail the current literature and to provide direction for future research. Additionally, broad practical applications are provided for both coaches and competitors to implement for competition. This chapter broadly addresses thesis aim 1 and provides background upon which to evaluate aim 2.

Chapter 3 investigates the current nutritional PW strategies implemented by competitors as obtained through a survey. Associations between strategies implemented and competitor characteristics were also examined. This chapter is presented in the format of a manuscript to be submitted to the *Journal of the International Society of Sports Nutrition* and contributes to the fulfilment of thesis aim 2.

Using the same survey from the previous chapter, Chapter 4 examines the current RT practices of competitors during PW where associations with competitor characteristics were also considered. This is the first study to examine the RT variables manipulated during PW as well as the magnitude and direction of change in these variables as compared with the week before PW (WBPW). This chapter is presented in the format of a manuscript to be submitted to the *Journal of Strength and Conditioning Research* and further contributes to addressing thesis aim 2.

Chapter 5 comprises of a study which assessed the concurrent validity of MT measurements of a portable ultrasound probe. This study evaluated the agreement between the portable Lumify device and the stationary Vivid S5 at five different sites encompassing the upper and lower limbs. This chapter is presented in the format of a manuscript to be submitted to the *Journal of Strength and Conditioning Research* and satisfies thesis aim 3.

Chapter 6, which concludes this thesis, is an overall discussion of the topic, synthesising the findings from the previous chapters to guide future researchers and practical applications for coaches and competitors.

Chapter 2: Peak Week Carbohydrate Manipulation Practices in Physique Athletes: A Narrative Review

Preface

Before exploring the current practices of athletes and the utility of research instruments in measuring important variables, an understanding of the background and current evidence surrounding peaking strategies for physique competition is necessary. This chapter lays the foundation for forthcoming chapters of this thesis by 1) critically examining and appraising the existing scientific literature relating to CHO manipulation practices in physique athletes prior to competition; 2) identifying research gaps and providing direction for future studies; and 3) providing broad practical applications based on the findings and physiological reasoning for coaches and competitors. To achieve these goals and fulfil thesis aim 1, and contribute to aim 2, a narrative review of the scientific literature relating to CHO manipulation practices of physique athletes during PW was conducted. This review also provides further background on peaking for physique sport and how the direct implementation of the CHO loading practices of endurance athletes may not be directly informative. Additionally, peaking strategies that involve the concurrent manipulation of fat, water, and electrolytes were uncovered and subsequently evaluated. Such information is important to inform future research and the practice of coaches and competitors, ultimately allowing for more efficacious peaking strategies to be implemented.

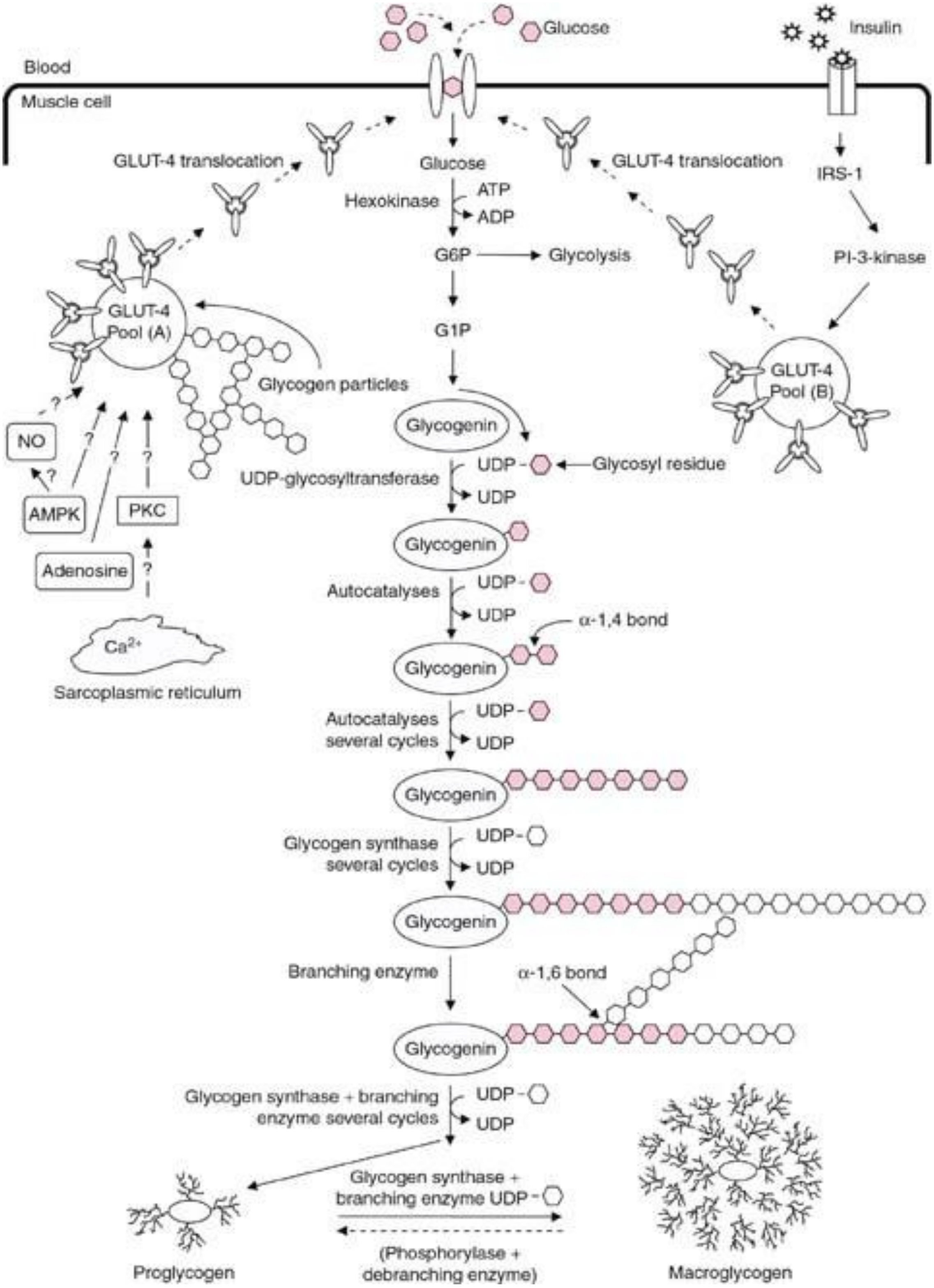
This chapter is currently in the second stage of revision with the *Sports Medicine – Open* journal.

2.1 Introduction

In competition, physique athletes are subjectively judged and ranked on muscle size, proportion, symmetry, bodyfat levels, and posing ability on the day. Accordingly, stronger performers maximise these variables by implementing appropriate pre-competition nutrition and training strategies [2, 35]. Within recent studies, contest preparation typically consists of at least four months of energy and thus CHO restriction in conjunction with increased training volumes [1, 3, 4]. The final week leading into competition is termed "PW" and involves further manipulation of nutrition and training variables to improve appearance, ostensibly by increasing muscle glycogen (and thus muscle size) while minimising subcutaneous water (supposedly enhancing muscular definition) and abdominal bloating [1, 4, 30]. Feasibly, a greater understanding of how to manipulate core nutritional factors around PW, notably CHO, could result in a more successful "peak" and improved performance.

Glycogen is the storage form of glucose derived from dietary CHO, of which skeletal muscle is the largest store within humans [6] (see Figure 2-1 Schematic representation of the glycogenesis pathway in skeletal muscle. for a graphical representation of the glycogenesis pathway). Muscle glycogen is heterogeneously distributed between and organised in three distinct subcellular compartments (intramyofibrillar, intermyofibrillar, and subsarcolemmal spaces) within myofibers [36, 37]. The time course for full intramuscular saturation through supercompensation is variable and likely occurs 36-48 hours following the cessation of the last exercise bout and CHO ingestion [19, 38, 39]. Amongst other factors, the rate of glycogenesis depends on total CHO and energy intake, sensitivity to and levels of serum insulin, prior glycogen depletion, muscle contraction-stimulated translocation of glucose transporters, gastrointestinal transport protein density, and relevant enzymatic activity [19, 20, 40–48]. Intramuscular glycogen size and density varies based on the subcellular site [49, 50] and total muscle glycogen content, with the larger macroglycogen particles stored with greater saturation two to three days into loading [51, 52]. Subcellular distribution is also dependent on training adaptations, where intermyofibrillar and subsarcolemmal glycogen content is greater in resistance-trained individuals than endurance-trained athletes [53, 54]. While CHO loading can increase muscle size through muscle glycogen content [17, 55, 56], the effect of individual glycogen particle volume and its subcellular distribution on muscle size and appearance is unknown. Feasibly, a better understanding of these physiological processes would allow physique athletes to adopt more specific nutritional and training strategies to enhance performance.

Figure 2-1 Schematic representation of the glycogenesis pathway in skeletal muscle.



Note. ADP = adenosine diphosphate; AMPK = adenosine monophosphate-activated protein kinase; ATP = adenosine triphosphate; Ca^{2+} = calcium ions; G1P = glucose-1-phosphate; G6P = glucose-6-phosphate; GLUT-4 = glucose transporter-4; IRS-1 = insulin receptor substrate-1; NO = nitric oxide; PI-3-kinase = phosphoinositide 3-kinase; PKC = protein kinase C; UDP = uridine diphosphate. From Jentjens & Jeukendrup [57]. The reader is also directed to the following reviews for further detail on the current understanding of the physiological processes and determinants of glycogenesis [14, 36, 57, 58]. Material is not part of the governing OA license but has been reproduced with permission. Determinants of Post-Exercise Glycogen Synthesis During Short-Term Recovery, Jentjens et al., Sports Medicine, 33, Springer Nature, 2012, reproduced with permission from SNCSC.

CHO loading protocols were first studied in endurance athletes, measuring performance and muscle glycogen levels, with muscle glycogen supercompensation observed following depletion and CHO loading [7–10]. Physique athletes subsequently adapted such strategies, manipulating CHO intake and training to enhance the appearance of muscle size [30]. However, muscle size changes in response to a CHO load are rarely an outcome measure in endurance training research, and the impact of loading on appearance is not relevant to endurance athletes. Muscle size increases in physique athletes have only been observed recently within a quasi-experimental design [56] and two case studies [5, 59], highlighting a paucity of empirical evidence to validate and guide these strategies. This review will highlight gaps in the literature, and subsequently provide suggestions for future research. Furthermore, relevant CHO loading trials are described while previously published information specifically relating to CHO manipulation strategies employed by physique athletes in PW are examined.

2.2 Carbohydrate Manipulation Practices in Endurance Athletes and Application to Physique Athletes

2.2.1 *Carbohydrate Loading Studies in the Endurance Literature*

The study of interactions between muscle glycogen content, diet, and exercise performance began with a series of Swedish experimental trials in the 1960s utilising the then novel percutaneous muscle biopsy technique [7–13]. The aim of this research was to investigate the effect of muscle glycogen as a stored energy substrate on endurance performance and the determinants of subsequent glycogenesis. While the effects of CHO loading on the appearance of physique (i.e., muscle size and definition) lack relevance to endurance athletes, the findings of these trials have implications for physique athletes seeking to increase muscle glycogen content and enhance muscle size. Of the designs which manipulated diet, muscle glycogen supercompensation was observed from the consumption of a predominantly CHO diet following exhaustive, glycogen depleting exercise [7–10]. Further experimentation with large CHO loads scaled to bodyweight (ranging from 9-12g/kg/day) for two to three consecutive days yielded significant muscle glycogen increases within the context of endurance training [15, 16, 60–63]. For example, McInerny et al. [15] depleted muscle glycogen content from 435±57 to 96±50mmol/kg dry weight (DW) (p<.01) in the vastus lateralis of six well-trained endurance athletes with an exhaustive cycling protocol. Two days of CHO loading with 12g/kg/day following the protocol resulted in supercompensation to 713±60mmol/kg DW ($p<.01$).

Similarly, Goforth et al. [16] implemented a three-day exercise and diet-induced (53±9g CHO/day) glycogen depleting protocol followed by a three-day repletion (720±119g CHO/day) without exercise in 14 male endurance athletes. Muscle glycogen content in the vastus lateralis increased from 408±168 to 729±222mmol/kg DW ($p\leq.05$). This supercompensated state was then maintained over the next two days with a moderate CHO intake (332±41g). The preservation of muscle glycogen following supercompensation [16, 64] could be advantageous for physique athletes who prefer to load CHO earlier in the week, further away from competition. Indeed, this protocol is known as CHO "front-loading", whereby competitors load at the start of PW which theoretically allows more time to adjust nutritional intake according to appearance [4, 30].

In another study, Nygren et al. [17] leveraged magnetic resonance imaging (MRI) to show vastus lateralis (+3.2%, $p=.001$) CSA and thigh circumference (+2.7%, $p=.009$) increases, coinciding with increased muscle glycogen content from 281±42 to 634±101mmol/kg DW in five male participants. These changes were due to a four-day glycogen depleting protocol involving a low CHO, high-fat diet with exhaustive exercise followed by four days of a high CHO and low-fat diet without exercise. While promising, a small sample size and accordingly reduced statistical power constrains the generalisability of the results. Nonetheless, these findings indicate that intramuscular glycogen content changes may affect muscle size.

Hypothetically, glycogen-mediated muscle size increases are driven by increased intramuscular water as water molecules are bound to each stored glycogen particle [65–67]. The water bound to each particle is variable and seemingly determined by hydration status [67], although glycogenesis is likely not impaired by dehydration [68]. In a dehydrated state, Olsson and Saltin [66] concluded that at least three to four grams of water are stored intramuscularly with each gram of glycogen; however, changes in water content were measured at the whole-body level using tritium labelled water and not directly in muscle tissue.

Within a cross-over trial that measured intramuscular water via muscle biopsy samples, Fernández-Elías et al. [67] created two experimental conditions where a CHO syrup was consumed with or without a rehydrating volume of water following cycling in the heat. Both groups consumed a CHO drink, with the rehydrating group consuming additional water to match individual fluid losses. Although both groups experienced similar glycogen repletion four hours following ingestion, muscle water content was higher in the rehydrating group than the non-rehydrating group (3814±222 vs. 3459±324g/kg DW, p<.05), with 17g of water bound to each gram of glycogen in the rehydrating group compared to only 3g in the non-rehydrating group; accordingly, substantially increasing muscle volume via concurrent CHO and fluid ingestion may be relevant in the context of physique athletes. However, as muscle water content did not reach baseline levels in either group, strategies involving dehydration may not be advisable. It is also unknown if emphasising hydration status in physique athletes could impact the appearance and performance in other ways, as some authors hypothesise that higher levels of body water increase ST which may obscure muscular definition, while acknowledging that the efficacy of strategies to manipulate hydration status require further examination [2].

2.2.2 *Dissimilarities between Endurance and Physique Athletes*

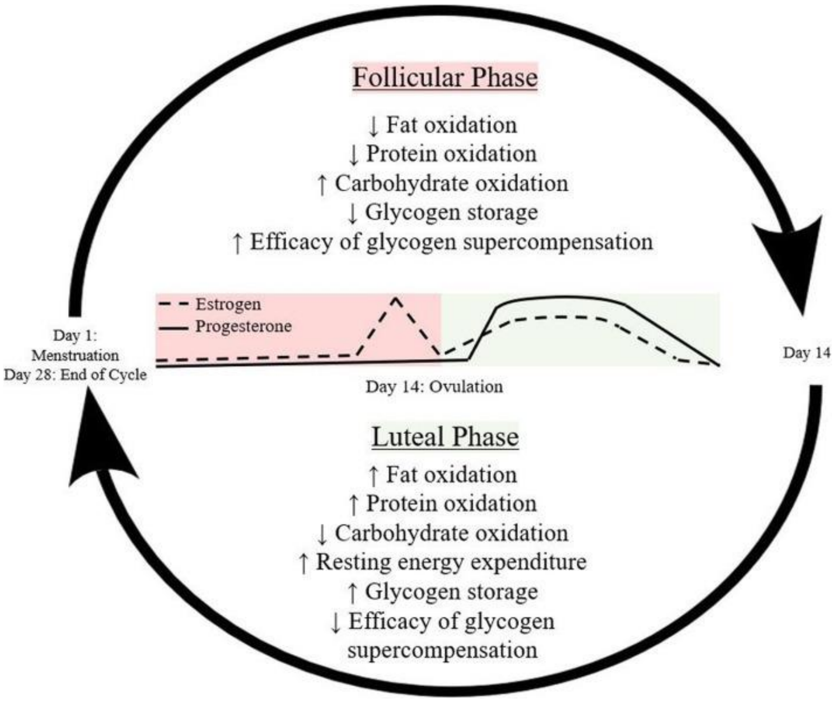
The theoretical underpinning and rationale for physique sport CHO loading protocols was born from endurance research. However, as endurance athletes are unconcerned with the aesthetic effects of CHO loading, research on the topic is not necessarily relevant or practical for physique athletes. Furthermore, the physiology of physique athletes at the end of contest preparation may be different from that of the typical endurance athlete. While some physique athletes potentially engage in high volumes of cardiovascular exercise [21, 69, 70], the prolonged periods of dieting, characterised by extreme reductions of both CHO and fat with the goal of achieving exceptionally low body fat, far below endurance athletes [59, 71–73] prior to CHO loading, differentiate the athletes. Additionally, physique athletes’ serum insulin concentrations decrease throughout contest preparation, considerably below the reference range in the week preceding competition [71, 72]. Given these physiological differences, it is difficult to directly apply literature-based endurance protocols to physique sport and doing so may not enhance aesthetic performance.

Unlike physique athletes during PW, the goal of the endurance athlete is to fully saturate muscle and liver glycogen stores to reduce the likelihood of muscle glycogen depletion and hypoglycaemia, and their negative performance effects [14, 74, 75]. Endurance athletes likely have greater glycogenesis rate and capacity compared to physique athletes in PW from their habituation to a high CHO diet and the absence of extensive energy restriction. Thus, implementing endurance-based protocols in physique athletes may lead to greater CHO consumption than can be digested and absorbed in the gastrointestinal tract and synthesised as glycogen before competition [42, 45, 76–78]. This is especially relevant as physique athletes theorise that when CHO consumption exceeds total glycogen storage capacity and/or the maximal rate of glycogenesis, glucose accumulates in other body compartments, including the interstitial space of the subcutaneous layer [4], increasing compartmental fluid volume from the osmotic effect of glycogen on water [66]. This rise in subcutaneous water is thought to blur definition, an effect known as "spilling over" which detracts from muscle definition – often called "conditioning" in bodybuilding circles [2, 4]. Hence, the implementation of CHO loads of the same magnitude as utilised by endurance athletes may not translate to competitive success in physique sport.

2.2.3 *The Female Menstrual Cycle and Implications for Physique Athletes*

In addition to the considerations described above, other physiological variables may be relevant. Notably, the effect of the menstrual cycle on glycogenesis following CHO loading in endurance athletes has been examined. For example, glycogen storage capacity decreases and the efficacy of supercompensation increases during the follicular phase, while the inverse occurs in the luteal phase [79] (see Figure 2-2 Schematic representation of key metabolic adaptations throughout the follicular and luteal phases of the menstrual cycle due to the physiological effects of oestrogen and progesterone.). Although the underlying mechanisms have yet to be fully understood, and a comprehensive examination is beyond the scope of this paper, menstrual phase-specific differences may be mediated by increased expression of oestrogens on glycogen synthase, insulin secretion, and adipocyte free-fatty acid oxidation [80–83]. Thus, muscle glycogen storage is theoretically elevated in the luteal phase compared to the early follicular phase [80]; however large CHO loads have induced supercompensation to similar values in both menstrual phases in some trials [62, 84], but not in others [85, 86]. Given this ambiguity, it is difficult to make menstrual cycle phase-specific recommendations for CHO loading magnitudes for female competitors. Furthermore, female competitors commonly experience menstrual cycle disruption and hypothalamic amenorrhea close to competition due to low adiposity and energy availability from extreme dieting [87–93]. Chronic low energy availability reduces oestrogen and progesterone levels below-normal physiological ranges [94] which may impair muscle glycogen storage following a CHO loading protocol.

Figure 2-2 Schematic representation of key metabolic adaptations throughout the follicular and luteal phases of the menstrual cycle due to the physiological effects of oestrogen and progesterone.



Note. Image © Springer Nature from Wohlgemuth & colleagues [66] under Creative Commons Attribution 4.0 International License https://creativecommons.org/licenses/by/4.0/

The theoretical variability in response to CHO intake during different phases of the menstrual cycle, or with hypothalamic amenorrhea, highlights the importance of individualised nutritional approaches to physique sport peaking. To better anticipate aesthetic changes and establish an individual response pattern, female competitors may benefit from experimenting with different CHO loads throughout the menstrual cycle during contest preparation (assuming it is present). Such an approach may provide information on CHO load magnitude and timing to inform future peaking strategies. Male competitors could also benefit from individualisation trial runs, potentially to a greater degree than their female counterparts, as their physiological response may be more consistent, although research is needed to confirm if relevant sex differences exist.

2.3 Observational Designs in Physique Athletes

2.3.1 *Cross-sectional designs*

While studies regarding CHO loading in physique competitors are likely more relevant than those concerning endurance performance, they are rare. Nevertheless, the few cross-sectional examinations that exist (summarised in Table 2-1 Summary of reviewed cross-sectional studies relating to peak week carbohydrate manipulation.) provide insight into peaking strategies employed by physique athletes. For example, in a recent survey of peaking strategies, Chappell and Simper [30] reported that 91% of a sample of 81 natural British bodybuilders (M=59, F=22) implemented some form of CHO manipulation. Of the PW strategies included in the 34-item questionnaire, CHO manipulation was the most employed, where restriction was followed by loading in competitors who utilised both. Qualitative responses indicated that both restriction and loading phases lasted up to four days, with the aim of depleting muscle glycogen stores before inducing supercompensation to increase muscle size. Specific competition-day strategies were also recorded, with 71.6% consuming high glycaemic index (GI) CHO 30-60 minutes prior to competition and 39.5% CHO loading. While surveying only a specific sample of physique athletes, these data indicate CHO manipulation strategies are prevalent and popular.

Similarly, albeit with a smaller sample, Mitchell et al. [24] interviewed seven experienced bodybuilders (10.4±3.4 years' experience and 14.3±5.9 competitions) to elucidate their adopted contest preparation nutritional strategies and associated rationale. Six participants used a modified CHO loading regimen involving increasing CHO and concurrently tapering training. Specifically, one participant detailed having a higher intake (400g) earlier in the week preceding two to three days of modest restriction (as low as 250g) before increasing CHO to 300-400g the day preceding competition. Four participants also reported implementing a CHO "backload", which involved a three-day depletion followed by loading. Notably, there was dissatisfaction with the protocol, due to its perceived inability to induce appreciable changes in appearance and the psychological distress caused.

Experiences of psychological distress (i.e., increased tension, anxiety, anger, depression, and fatigue) are in line with studies of bodybuilders indicating prominent mood disturbances around the end of contest preparation [72, 87, 95]. Mood states likely degrade during contest preparation due to the extended period of energy restriction leading to low energy availability and the very low bodyfat levels achieved, far below competitors' lower intervention point [96]. Mood disturbances could also be attributed to competition-day anxiety, potentially amplified by CHO loading prompting fears of "spilling over". Researchers have proposed that psychological stress can negatively affect appearance through increased secretion of adrenocortical hormones, intensifying sodium reabsorption and potentially expanding extracellular fluid volumes [2, 97];

however, the effect of such water retention on appearance is unexplored. Thus, further investigation into the effects of CHO manipulation strategies on mood disturbances over the entirety of PW and quantifiable physique changes are required to determine associations of mood states with physique sport performance.

Table 2-1 Summary of reviewed cross-sectional studies relating to peak week carbohydrate manipulation.

Study (year)	**Sample**	**Methods**	**Relevant Findings**
Mitchell et al. (2017) [24]	7 experienced (min. national level), natural male bodybuilders (36.7±14.6yrs)	Subjective interviews regarding pre-competition training and nutrition, including "PW", were conducted by members of the research team.	6 participants most recently utilised a modified CL strategy. 4 participants had also previously implemented a traditional CL protocol which was described as not resulting in any discernible changes in appearance while inducing psychological distress.
Chappell et al. (2018) [30]	81 (59 M, 22 F) competitive British bodybuilders (M=33±12, F=34.7±9.7yrs)	Distribution of a 34-item questionnaire regarding pre-competition training and nutrition to the combined 2016 and 2017 British Natural Bodybuilding Federation competitor dataset.	PW CHO manipulation was the most prevalent strategy. Amongst competition day strategies, high GI CHO pre-stage and higher CHO consumption were most prevalent.

Note. PW = peak week, CL = carbohydrate loading, CHO = carbohydrate, GI = glycaemic index.

2.3.2 *Single-subject Designs*

While long-term case studies examining bodybuilders pre- and post-competition have been published, few report peak-week strategies or their possible effects [72, 91, 98]. A recent case study by Barakat et al. [5] is the most detailed examination of the effects of CHO manipulation on body composition outcomes to date; specifically, a natural male competitor followed a PW protocol devised by the research group [2]. CHO consumption on the first day of data collection (nine days out from competition) was 297g, which was reduced to 88, 73, and 88g the preceding three days of depletion (six to four days out), respectively. CHO loading involved 582g and 573g the following two days (three to two days out), respectively, before tapering to 399g the day before competition. The pattern of fat intake was inverse to CHO, where the highest intakes (86-132g) occurred during CHO depletion. Finally, water intake also followed a somewhat similar pattern to CHO consumption from nine to two days out, with the lowest intake on the final day before competition. This was described as an attempt to reduce body water whilst preserving intramuscular glycogen and triglyceride stores with the cessation of physical activity.

Overall, there were favourable outcomes due to these combined strategies. The sum of ultrasound measures of MT collected from four sites (distal and proximal quadriceps, chest, and elbow flexors) were positively associated with CHO intake from the previous day throughout peak weak (τ=.733, p=.056). Prior to depletion, the sum of MT was 18.56cm which increased to 18.99cm the morning of competition. Relative quadriceps and chest MT increased, while elbow flexors decreased when comparing measurements from the previously mentioned data collection points. Indeed, total MT (+2.32%) and ST (-0.67%) alterations were observed from the start of the protocol, as desired. With that said, it is challenging to untangle the individual effects of any single aspect of the combined peaking strategy within a case study design, which included manipulations of CHO, water, and dietary fat.

For instance, it is debatable whether CHO restriction is required to induce subsequent maximal glycogen supercompensation. Notably, equivalent and maximal muscle glycogen supercompensation can be achieved without prior cessation of dietary CHO [38, 39] which may indicate depletion is not necessary, and leaves the question of whether comparable body composition changes could have been achieved with a more consistent CHO intake. Likewise, the strategy employed by Barakat et al. [5] of increasing fat intake while depleting CHO is known as “fat-loading” and is an attempt to increase intramuscular triglyceride content and thus muscle size. While no experimental evidence exists on fat loading, this approach is rationalised by the comparable energy contents of intramuscular triglyceride being higher than glycogen [99]. However, as appreciable muscle size changes are likely driven by the water bound to glycogen rather than its energy density, the extent to which fat-loading increases muscle size may be negligible and the practice may simultaneously increase ST, as there is no known mechanism for preferentially storing triglycerides intramuscularly rather than subcutaneously.

Most importantly, it is difficult to determine the 'visual' effects of this protocol on the participant's physique, as there was no subjective judging or quantification of the competitor's appearance. While anthropometric measurements indicated success, there are no data which correlate anthropometric changes with visual changes. Notably, the lack of visual, subjective assessments (e.g., photograph physique score changes on a 1-10 scale by a panel of qualified physique judges) is a persistent limitation of physique athlete case studies.

Another case study, conducted by Schoenfeld et al. [59], documented the effect of CHO loading on MT during contest preparation. In the final week before one of the participant's four competitions, ultrasound MT was obtained at four sites (elbow flexors and extensors, midthigh and lateral thigh). Measurements were collected following a three-day depletion phase, the subsequent two-day loading phase, and finally one hour after the previous measure following CHO ingestion. The athlete decreased energy to 1474-1642kcal/day and CHO to 20-46g/day during depletion, lower than the lowest two-week rolling average intake during contest preparation (1953kcal and 104g/day), which was then increased during loading to 3374-3537kcal/day and 449-483g/day, for energy and CHO, respectively. The authors reported 5% and 2% upper arm and quadriceps MT increases, respectively, at the post-loading measurement compared to the post-depletion phase, and no changes following the post-loading 50g CHO bolus. While MT increased after loading, the increases were observed post-depletion. Since, the authors did not provide baseline MT data before depletion, whether the post-loading MT values improved upon pre-depletion values remain unknown. Thus, the efficacy of the strategy cannot be assessed since it is possible that similar final MT values could have been achieved without a PW strategy. Future research should compare baseline outcome measures with post-depletion and loading values to better evaluate peaking strategies.

Additionally, further case studies provide indirect insight into the effects of CHO manipulation on body composition. For example, Rossow et al. [72] followed a white, male professional natural bodybuilder for 12 months pre- and post-competition. The authors reported increased body water (60.48 to 62.12L) and decreased body fat (6.6 to 4.5%) and sum of ultrasound ST (11 sites, 0.85 to 0.68cm) a week before competition versus a month prior. These changes corresponded with the highest weekly mean energy intake and a marked blood glucose increase from three months prior (52 to 72mg/dL). While total CHO intake was unreported, the increased energy intake, body water, and blood glucose may be attributed to increased CHO as part of a peaking strategy. Similarly, Halliday et al. [88] reported a modest increase in mean CHO intake to 3.8g/kg the final week of a female figure competitor's contest preparation (week 20) from 3.4 and 2.7g/kg at weeks one and 10, respectively. Energy intake was also the highest recorded since week three of contest preparation, corresponding with a skinfold thickness reduction from four weeks prior. However, as CHO intake was reported as weekly means and not as specific daily intakes, it is difficult to discern if a specific peaking protocol was implemented. Despite indications of potential CHO manipulation in both Rossow et al. [72] and Halliday et al. [88], it is difficult to interpret which specific protocols were implemented and their potential efficacy.

While a unique nutritional intake during "PW" which includes CHO manipulation itself is a popular strategy among physique athletes [30], the specific pattern and magnitude of CHO can vary widely. For example, Steen et al. [23] documented the use of a traditional CHO loading regimen by a drug-enhanced male bodybuilder. The competitor restricted CHO for three days before loading with 300g the day before and on competition day. Likewise, Hickson et al. [100] also detailed the use of a similar protocol by another enhanced male bodybuilder, who depleted CHO for two days before loading with only 100g for the next three days before competition. Contrastingly, a very high intake of CHO was captured within a clinical case report of a professional bodybuilder admitted to intensive care due to bilateral lower limb paralysis [101]. The athlete reported consuming minimal CHO the month preceding competition before loading with 800g of high GI CHO on competition day. While no anthropometric data was collected in these case studies [23, 100, 101], they highlight substantial variability in PW approaches. All relevant case studies are summarised in Table 2-2 Summary of reviewed case studies relating to peak week carbohydrate manipulation in physique athletes.

Table 2-2 Summary of reviewed case studies relating to peak week carbohydrate manipulation in physique athletes.

Author (year)	**Participant**	**Methods**	**Relevant Findings**
Hickson et al. (1990) [100]	White, drug enhanced male amateur bodybuilder (27yrs)	Collection of daily food records over the course of a 30-day contest preparation period.	Implementation of a 2-day CHO restriction period followed by 3-days of moderate intake in the week before competition. Consumed mainly CHOs prior to stepping on stage. Placed in top 3 of competing weight class, no body composition outcomes measured.
Steen et al. (1991) [23]	White drug enhanced male amateur bodybuilder (25yrs)	Collection of five-day food records at 6- and 5-months, and 1 week pre-competition.	Implementation of 3-day CHO restriction, followed by 3-days of moderate intake in the week before competition. No body composition outcomes measured.
Rossow et al. (2013) [72]	White, natural male bodybuilder (26yrs)	Monthly body composition assessment (via 4CM and SFs) and collection of dietary records for 6 months pre-and-post competition. On the month of competition, data was collected 1 week pre-competition.	↑ FFM and TBW with ↓ ΣUST and BF% (both 4CM and SFs) in month of competition compared to previous month.
Halliday et al. (2016) [88]	White, natural female amateur figure competitor (26yrs)	Collection of SF thickness measures on 8 and 4 occasions pre-and-post competition, respectively. Daily self-reported dietary intake and BM.	↓ ΣSF thickness in the final week before competition from four weeks prior, coinciding with a modest ↑ in energy and CHO intake.
Lapinskienė et al. (2017) [101]	Natural male professional bodybuilder (28yrs)	Case report of a competitor admitted to hospital following bilateral lower limb paralysis.	The competitor consumed 800g of high GI CHO on the day of competition following a month of severe CHO restriction. The exact amount of CHO consumed pre-stage is unknown.
Schoenfeld et al. (2020) [59]	White, male amateur bodybuilder (25yrs)	Monthly body composition over an 8-month pre-competition and 4-month post-competition period with daily nutrition logs completed by the participant. The peaking strategy for 1 of the participant's 4 competitions was detailed.	↑ in UMT observed following 3-day CD and 2-day CL phases.
Barakat et al. (2022) [5]	Middle Eastern-American, natural male professional bodybuilder (29yrs)	Collection of dietary intakes, hydration status, and body composition of the participant on 6 days over an 8 day "peaking" period.	A 3-day CD followed by a 2-day CL and 1 day tapering phases implemented prior to competition. UMT positively correlated with CHO intake. ICW:ECW peaked on the final day of CD, ↓ during CL and ↑ to slightly above baseline value on competition day.

Note. CHO = carbohydrate, 4CM = four compartment model, SF = skinfold, ↑ = increased, FFM = fat-free mass, BM = body mass, TBW = total body water, ↓ = decreased, Σ = summation, UST = ultrasound subcutaneous tissue thickness, GI = glycaemic index, CD = carbohydrate depletion, CL = carbohydrate loading, UMT = ultrasound muscle thickness, ICW:ECW = intracellular water to extracellular water ratio.

2.3.3 *Multiple-subject Designs*

While the physique-sport literature predominantly consists of case studies, there are some multiple-subject studies which may provide more generalisable findings (see Table 2-3 Summary of reviewed group-level observational studies relating to peak week carbohydrate manipulation in physique athletes. for a summary of multiple-subject observational studies). Bamman et al. [55] followed six male bodybuilders for twelve weeks preceding competition. Unfortunately, despite stating a CHO load commenced 72 hours before competition and reporting a mean CHO intake (290±73g) from a three-day dietary profile completed the same day as the commencement of loading, day-to-day dietary intake was undisclosed. In the final 24-48 hours preceding competition during CHO loading, ultrasound bicep MT reportedly increased (+4.9%), while the ST measure from the same site had decreased (-29.4%) from six weeks prior; however, the results should be interpreted with caution, since neither met the threshold for statistical significance ($p>.05$). Further, due to the unclear results, the time between data collection, and the lack of detailed day-to-day nutritional information, direct causal inferences cannot be drawn from this study.

In two studies which assessed dietary intakes but did not track body composition changes of female bodybuilders, CHO intake increased in the immediate days prior to competition [22, 102]. Walberg-Rankin et al. [103] reported increased CHO consumption two days before competition compared to data collected one and three weeks prior. Specifically, this involved an almost twofold group level CHO intake increase (202.7 to 385.9g, $p=.001$), accounting for 83% of total energy. Similarly, Lamar-Hildebrand et al. [22] drew comparisons between in-season and off-season bodybuilders and made similar observations. The competitors increased energy intake (1283±789 to 2228±1192kcal) on the weekend of competition, driven by higher CHO consumption (222±149 to 359±194g). While these group-level observational studies demonstrate the use of CHO loading strategies among female bodybuilders and their magnitudes, the efficacy of these practices cannot be determined due to the absence of body composition data. To summarise, both case study and multiple-subject observational studies indicate CHO manipulation is a common strategy among physique athletes; however, the positive impact on anthropometry hinted by this literature remains an untested assumption.

In addition to CHO manipulation, physique athletes may concurrently manipulate electrolyte and water intake when peaking [104]. This practice is intended to increase intracellular water (ICW) while decreasing extracellular water (ECW), supposedly to expand muscle and reduce subcutaneous water, respectively [2, 5, 31]. This theory is rationalised by the high concentration of sodium and potassium in ECW and ICW, respectively, associated with cell fluid volume (i.e., the sodium potassium pump) [105]. Consequently, bodybuilders and researchers propose that increasing potassium while reducing sodium intake alters cellular concentrations of these ions, which when combined with increased muscle glycogen content, creates an osmotic gradient for interstitial water to be drawn into muscle [2, 5, 31]. The proposed outcome of such process is a favourable ICW:ECW ratio, which may enhance the appearance of muscle fullness and definition [1]. As such, techniques to estimate the distribution of fluid compartments in the context of peaking are of interest to the physique sport population [5, 31].

To examine if such fluid shifts are indeed achieved by bodybuilders via peaking protocols, researchers have adopted bioelectrical impedance analysis (BIA) and bioelectrical impedance spectroscopy (BIS). For example, Nunes et al. [31] employed a single-frequency BIA device to compare competition day body water fraction changes from the day prior in 11 male competitors. Each participant achieved simultaneous ICW increases and ECW decreases, increasing their ICW:ECW ratio as presumably intended. While the lack of dietary data is a limitation, the authors hypothesised the bodybuilders manipulated CHO, electrolytes, and water, causing these outcomes. While promising, methodological limitations complicate these findings [31]. Particularly, hydration status, diet, and acute water intake were, understandably, uncontrolled. Unfortunately, single-frequency BIA results are sensitive to and impacted by these variables [106]. Additionally, and most importantly, single-frequency BIA cannot distinguish between intracellular and extracellular fluid compartments, as multiple frequencies, from devices such as multi-frequency BIA or BIS, are required to do so [107]. Thus, a prediction equation developed by Matias et al. [108] was utilised by Nunes et al. [31]; unfortunately, since the equation was derived from high level non-physique athletes, disparities in the body geometries between the sample used for calibration and physique athletes probably inflated the already unacceptably high expected fluid compartment error estimations (±3.6-6kg of fluid). Further, the testing conducted by Matias et al. [108] to develop the equation were highly standardised, whereby participants were required to have been fasted for 12 hours, be euhydrated, and not have exercised in the past 15 hours, which likely differed from the testing conditions of Nunes et al. [31].

These methodological shortcomings and error rates confound interpretation, and likely account for the highly homogenous competition day ICW:ECW ratios (1.92±0.01L) reported by Nunes et al. [31], while also highlighting the difficulty of standardising BIA measurements of physique athletes during PW.

Compared to the BIS-derived raw bioimpedance results from the aforementioned case study by Barakat et al. [5], a smaller competition day ICW:ECW ratio (+3.87%) increase was reported from the day prior in comparison to Nunes et al. (+20%) [31], likely due to the different devices employed. BIS devices possess superior predictive capabilities compared to BIA as they use a spectrum of frequencies to differentiate ICW and ECW [107, 109], making the use of regression-derived population-specific prediction equations to estimate fluid compartments unnecessary [107, 110]. However, limitations still exist even within BIS. Specifically, device validation in different populations is required, as inherent body geometry and composition variations exist [107]. This limitation was present in Barakat et al. [5], as the extreme body geometry and composition of the participant likely diverged from the assumptions of the BIS device's in-built equations.

Notwithstanding this limitation, an increased competition day ICW:ECW ratio from the day prior was also reported by Barkat et al. [5] who also examined the effects of their peaking strategy on fluid compartment shifts. Curiously, however, the highest reported ICW:ECW ratio was three days prior to competition, the morning after the depletion phase where MT was the lowest and ST was the second highest. Given the relationship proposed by Escalante et al. [2], Barakat et al. [5], and Nunes et al. [31] that a high ICW:ECW ratio should coincide with the best combination of MT increases and ST decreases, and therefore best appearance, it is plausible that either the proposed relationship is incorrect or that bioelectrical impedance derived ICW and ECW may not accurately represent body water changes during PW.

Indeed, regarding this proposed relationship, attempting to induce such fluid shifts with the restriction of water and sodium while loading potassium – as commonly practiced by physique athletes – could even degrade aesthetic performance. Dietary sodium reductions may slow small intestine glucose absorption due to its down-regulating effect on the concentration of brush border GLUTs [42–44], whilst also reducing the concentration of sodium ions required for SGLT1 cotransport of glucose [111–114]. Additionally, SGLT1 and GLUT5 density and activity are lowered with a CHO-free diet [103]. While these adaptations begin within four hours of CHO exposure [115], it may take several days for appreciable increases in SGLT1 expression to occur [116], potentially slowing glucose absorption when initially loading CHO following depletion and sodium restriction. Furthermore, blood pressure decreases during the final weeks before competition [72], which would likely be compounded by sodium restriction [117]. Such blood pressure reductions would be disadvantageous for competitors seeking transient muscle size and definition increases from active hyperaemia and the accumulation of metabolites following a pre-stage “pump-up” routine [4, 118, 119]. Thus, it may even be advisable to increase sodium consumption on competition day for certain divisions due to its acute effect on raising plasma volume and blood pressure (albeit requiring further research to confirm the efficacy of this strategy) [4, 120–122].

This strategy is often justified by the misconception that ICW and ECW are equivalent to intramuscular and subcutaneous water, respectively, and that by increasing ICW via glycogenesis, water restriction will preferentially lead to higher proportional ECW decreases [2]; however, including water restriction as part of a peaking strategy may be deleterious for competitors. While intracellular fluid is indeed the major skeletal muscle fraction, it is also comprised of a non-negligible amount of extracellular fluid [123, 124]. Skeletal muscle is approximately 70-75% fluid [125, 126], and total muscle water content is reduced during dehydration [127, 128], potentially affecting muscle size. Intravascular plasma is also extracellular fluid [123, 129, 130]; thus, blood volume reductions from water restriction may impair the delivery of glucose to myocytes and therefore the efficacy of CHO loading. While the osmotic effect of glucose induces acute water shifts within these compartments [131], water balance and the concentration of ions are tightly regulated by homeostatic mechanisms [132, 133]. It has been proposed that the temporal lag in re-establishing homeostasis following water loading could be leveraged to increase urine output and therefore water excretion during subsequent restriction to reduce ECW. Subsequently, the increased intramuscular glycogen from CHO loading may preserve or increase muscle water (via an increased ICW:ECW ratio) and thus size [2]. However, there was a moderate relationship between total body water (TBW) and ECW ($r=-.44$. $p<.05$) in physique competitors with varied approaches to water intake during PW as recently observed by Escalante et al. [34]. Indicating that the proportion of ECW is greater when TBW is reduced, which suggests that the competitors were not able to preferentially reduce ECW through peaking strategies. As the appearance of the participants were not subjectively evaluated, in addition to a lack of experimental evidence, the combined effect of water and electrolyte manipulation on the appearance of muscle and its time course is unknown. Furthermore, Escalante et al. [2] recommend that water and CHO manipulations be planned and practiced before PW, and to be kept relatively constant if such practice runs are not feasible, highlighting the potential for performance decrements with such strategies.

Notably, a cross-sectional study examining the diets and metabolic profiles of male and female high-level drug-enhanced bodybuilders found that blood sodium levels were within normal ranges 24 hours prior to competition [134]. This was despite the deliberate restriction of dietary sodium, evidenced by strategies such as the deliberate shift from tap water to distilled, to reduce fluid retention. As such, it seems unlikely that electrolyte and water manipulation substantially alter the concentration of sodium ions to induce the desired fluid shifts. In fact, if successful, such practices may increase the risk of life-threatening conditions such as hyperkalaemia and rhabdomyolysis, especially when combined with diuretics and anabolic steroids [135, 136]. Based on the physiological reasoning provided and the previously discussed studies not observing competitor appearance changes [5, 31], it is difficult to assert that such fluid shifts and the nutritional strategies intended to induce them occur as expected or are favourable for physique sport performance.

In summary, while observational studies document the implementation of CHO manipulation protocols by physique athletes and suggest that these techniques may increase muscle size, limited study numbers and methodological concerns confound interpretation. Furthermore, we present our arguments against certain strategies (such as water and electrolyte manipulation) which are predicated on physiological mechanisms rather than empirical evidence. Such proposed strategies may indeed improve appearance; however, to determine if that is the case requires rigorous and controlled investigations.

Table 2-3 Summary of reviewed group-level observational studies relating to peak week carbohydrate manipulation in physique athletes.

Author (year)	**Sample**	**Methods**	**Relevant Findings**
Lamar-Hildebrand et al. (1989) [22]	10 females (6 bodybuilders, 4 non-competitors)	3-day food records and self-report questionnaires on weeks 8, 4, and 2 prior to and the weekend of competition.	Competitors increased total energy and CHO intake on the week and weekend of competition. No placing or body composition data reported.
Bamman et al. (1993) [55]	6 enhanced male bodybuilders (25-29yrs)	Collection of 3-day food records and bicep UMT and UST on weeks 12, 6 and 0 pre-competition.	All competitors engaged in a CL protocol 72 hours before competition. From weeks 6 to 0 before competition, UMT↑ while UST↓ (both non-significant).
Walberg-Rankin et al. (1993) [103]	6 female bodybuilders (27.3±5.1yrs)	Collection of food records from 28 to 26, 9 to 7, and 2 to 1 day(s) pre-competition, competition day to 2 days-post, and 19 to 21 days post-competition.	↑CHO and ↓fat consumption in the 2 days prior to competition in comparison to 9 to 7 days pre-competition.
Nunes et al. (2022) [31]	11 untested male state-level bodybuilding and physique competitors (28.8±4.1yrs)	Body composition assessment of competitors in the afternoon the day before and on competition day. Relevant outcome measures include girths and BW fractions derived from single-frequency BIA. No dietary intakes recorded.	No changes in girths and significant ↑ in ICW, ICW:ECW, and TBW were observed. Hypothesised by authors that this was induced by CHO manipulation.

Note. CHO = carbohydrate, UMT = ultrasound muscle thickness, UST = ultrasound subcutaneous tissue thickness, CL= carbohydrate loading, ↑= increased, ↓ = decreased BIA = bioelectrical impedance analysis, ICW = intracellular water, ICW:ECW = intracellular water to extracellular water ratio, TBW = total body water.

2.3.4 *Experimental Designs*

2.3.4.1 A Quasi-experimental Design in Physique Athletes

Arguably the most relevant study of PW was conducted by de Moraes et al. [56]. The researchers stratified 24 male bodybuilders into two groups, delineated by whether CHO was loaded or not before competition. Notably, MT appeared to increase following a 24-hour CHO load after three days of depletion. Both groups increased daily CHO intake following depletion, with the loading group increasing to 9.0±0.7g/kg BM from 1.1±0.4g/kg BM compared to the non-loading group increasing to 5.2±0.9g/kg BM from 0.9±0.6g/kg BM. The loading group increased both elbow flexor (+3.1%, $p<.05$) and triceps brachii (+3.4%, $p<.05$) MT, whereas there were no increases within the non-loading group. The loading group also improved their physique silhouette scores on a scale developed by Castro et al. [137]. The competitors were evaluated using the silhouette scale by seven official bodybuilding judges blinded to the intervention, indicating that CHO loading may positively influence subjective measures of muscle size. However, a limitation of the silhouette scoring system employed is that any changes in the appearance of leanness may not be distinguished or quantified. Furthermore, skinfold measures were not collected at the second point of data collection, thus the effect on ST could also not be determined. For future research, assigning a score for both muscle size and definition when subjectively evaluating the appearance of competitors may allow for further detail on the effects of peaking strategies to be uncovered.

Measures of abdominal and epigastric symptoms were also collected and compared between groups [56]. Constipation was the most prominent gastrointestinal symptom in both groups following depletion, which persisted within the non-loading group at the second point of data collection (2.00±0.67 to 2.13±0.81, $p>.05$). Contrastingly, incidences of constipation decreased in the loading group (1.89±0.57 to 1.53±0.72, $p<.05$) while diarrhoea increased (1.22±0.42 to 1.93±0.37, $p<.05$). This is potentially the result of drastically increasing CHO beyond the emptying rates of the stomach and gastrointestinal tract [42], where glucose transporters are seemingly downregulated following CHO restriction [138]. Interestingly, both groups' total scores of gastrointestinal symptoms increased (loading group=14.9±0.22 to 16.93±0.24, $p<.05$ vs. non-loading group=13.88±0.28 to 14.21±0.31, $p<.05$). This finding may be indicative of competition stress, irrespective of CHO intake, since acute stressors can slow gastric emptying rates [139]. Thus, competition stress may contribute to the slowing of gastrointestinal glucose absorption and subsequent glycogenesis, as well as to gastrointestinal distress. The findings of de Moraes et al. [56] further highlight the utility of experimenting with different CHO loads prior to competition, as individualising the CHO loading protocol (i.e., the timing, quantity, and type of CHO) could maximise the rate of glycogenesis while minimising gastrointestinal symptoms. Such experimentation may confer some physiological and psychological benefits [140–142] associated with intermittent dieting or “refeeding”, while allowing for competitors to become (re)accustomed to large volumes of CHO.

2.3.4.2 An Experimental Design

In the only experimental design to date, Balon et al. [18] intended to replicate a CHO loading protocol employed by bodybuilders with a crossover design. In conclusion, no significant muscle girth increases were reported following a two-day CHO loading regimen. The protocol involved a three-day isoenergetic, low CHO diet (10% of diet) followed by an isoenergetic, high CHO diet (80% of diet) two days during the experimental arm, while the control arm participants consumed an isoenergetic, moderate CHO diet (55% of diet).

Unfortunately, this study did not replicate the PW conditions of bodybuilders. Notably, the mean body fat percentage of the participants was 10±1%, which is much higher than the values of 4.4-6.3% typical of high-level male bodybuilders in the final week of competition [5, 59, 93, 134]. The participants also had not dieted with a reduced CHO intake for months prior to the study. This detail is salient as contest preparation may induce chronic glycogen depletion which could subsequently impair glycogenesis. Further, the participants consumed an isoenergetic diet during depletion, whereas CHO loading physique athletes are initially in a severe energy deficit which would cause greater glycogen depletion prior to loading [1]. The participants also altered the proportion of CHO rather than increasing their energy intake with additional CHO, which may not have maximised glycogenesis [19, 20].

Furthermore, a high-volume RT protocol of 30-35 sets to or very close to failure was performed daily during depletion, which may vary from typical practices of bodybuilders (~50% higher than that used by natural bodybuilders [21]) who often decrease training stress during PW [22–24]. Such high set volume and intensity during CHO restriction may have caused muscle damage and sarcolemmal membrane disruption, possibly impairing glycogenesis in the subsequent CHO load [25–29].

Indeed, it may be advisable to not train with high volumes, in close proximity to failure, as well as not performing exercises which train muscles at long lengths under heavy eccentric loads [25–29, 143–145] during PW to avoid excessive muscle damage.

Finally, while the authors did not report muscle girth increases, it is plausible that a visual change in the appearance of the muscle and overall aesthetic could have occurred. Therefore, further ecologically valid experimental research examining visual changes by judges of the relevant physique sport division with body composition measures are required to determine the effects of peaking strategies on bodybuilding performance. Both experimental designs are summarised in Table 2-4 Summary of reviewed experimental studies relating to peak week carbohydrate manipulation in physique athletes..

Table 2-4 Summary of reviewed experimental studies relating to peak week carbohydrate manipulation in physique athletes.

Author (year)	Sample	Study Design	Methods	Relevant Findings
Balon et al. (1992) [18]	9 resistance trained males (23±4.4yrs)	Crossover	Experimental arm: 3-days of isoenergetic, low-CHO diet and intense RT followed by 2-days of isoenergetic, high-CHO diet & tapered RT. Control arm: 3-days of isoenergetic, moderate-CHO diet and intense RT followed by 2-days of isoenergetic, moderate-CHO diet & tapered RT.	No significant changes in muscle girths between groups.
de Moraes et al. (2019) [56]	24 (15 CL, 9 NCL) South American, untested, male bodybuilders (CL=27.3±5.0, NCL=26.2±4.9yrs)	Quasi-experimental	Stratification of competitors into CL or NCL groups. Collection of UMTs, circumferences, gastrointestinal symptoms, and mood states following 3-days GD and 1-day CL. Photographs of the participants at data collection were rated by 7 federated bodybuilding judges according to a photo silhouette scale [129]. Food diaries of the final 4 days pre-competition were collected.	Both groups ↑ energy and CHO intake from the GD period for which the magnitude was greater in the loading group. ↑ in UMT, circumferences, and silhouette scores were observed in the CL group. Mood disturbances ↑ slightly in both groups, as did gastrointestinal symptoms which were greater in the CL group.

Note. CHO = carbohydrate, RT = resistance training, CL = carbohydrate loading, NCL = non-carbohydrate loading, UMT = ultrasound muscle thickness, GD = glycogen depletion, ↑ = increased.

2.4 Practical Applications

Based on the current evidence, making specific peaking recommendations to improve physique sport performance is difficult. Nevertheless, some practical guidance to prospective athletes and coaches looking to adopt peaking strategies can be provided. For example, loading with 3-12g/kg BM of CHO may increase muscle size; however, the exact amount likely is dependent on the requirements of the individual and division of competition (i.e., male bodybuilders likely require more CHO than bikini competitors due to a greater emphasis on muscularity). Thus, it is likely advisable that competitors and coaches test different CHO loading magnitudes and strategies well in advance of competition day in comparable physiological conditions (i.e., very low levels of adiposity, typically one to two months away from competition). Visual changes and the time course for the CHO load to “take effect” and alter the competitor’s physique as well as the quantity and type of CHO consumed should be recorded to inform future PW strategies to increase their reliability. Such practice runs also present competitors the opportunity to habituate to high acute CHO intakes and reduce gastrointestinal stress [19, 42]. Additionally, using information from previous competitions to guide future practice is recommended. Establishing an individual response pattern could be especially valuable for female competitors whose rate of glycogenesis and glycogen storage capacity may be impacted by disruptions to the menses typically seen in contest preparation [87–93]. Thus, it would be prudent for coaches and competitors to experiment with differing loads during different phases of the menstrual cycle (or in its absence) prior to competition to better anticipate visual changes.

During PW, avoiding strategies that drastically alter nutritional variables from previous weeks may be sensible. These alterations, which include the substantial manipulation of CHO, water and electrolytes, and the introduction of new foods, could risk unpredictable and deleterious effects if not executed appropriately. For example, loading with too much CHO may reduce the appearance of muscle definition. Additionally, depleting glycogen prior to loading may be unnecessary to achieve maximal glycogen supercompensation [38, 39] and thus, competitors can avoid extremely low CHO intakes during PW which may incur unnecessary psychological stress and reduce training quality [56, 72, 87, 146]. However, without experimental data to confirm our suppositions, it is possible that this approach could be advantageous in some cases (i.e., a competitor requiring lower body fat benefiting from low energy intake during depletion). Likewise, restricting water and sodium have the potential to reduce muscle size and vascularity, and impair CHO loading, while overconsumption may lead to unwanted water retention and obscuration of muscle definition.

As physique competitors typically incur psychological distress close to competition [56, 72, 87] and given the proposed relationship between stress and water retention [2], stress management may be an overlooked area to improve performance. Thus, to minimise stress, establishing an individual response pattern and reducing the number of variables manipulated may benefit the competitor. Psychological distress may also be amplified by travel-related stressors, whereby competitors could travel earlier and become accustomed to the new environment and time zone (if applicable) to lessen the impact on performance. Mindfulness techniques which have been shown to moderately reduce stress in non-clinical populations (Hedges' g=.55, p<.01) [147] may also be of interest to competitors; however, further research examining such techniques in the context of contest preparation and PW are required to make concrete recommendations.

The manipulation of training variables should be considered when attempting to induce muscle glycogen supercompensation. As glycogenesis may be impaired by high degrees of muscle damage, training with high volumes, very close to failure, or performing exercises which place muscles at long lengths or under heavy eccentric loads should be avoided [25–29, 143–145]. It is also advisable that competitors consume adequate energy predominantly from high GI CHO with minimal fibre to maximise glycogenesis while minimising gastrointestinal distress [42, 148]. Finally, as muscle glycogen levels remain stable for up to five days following supercompensation even with the cessation of exercise [16, 64], ceasing RT and cardiovascular exercise during and after loading may help maximise and preserve intramuscular glycogen for competition.

As some divisions emphasise muscularity of certain muscle groups (i.e., upper body for physique and lower body for bikini competitors), preferential supercompensation of glycogen may be achieved in these muscle groups if they are depleted to a greater degree via RT. As the rate of glycogenesis is influenced by prior glycogen depletion and muscle contraction-stimulated translocation of glucose transporters [19, 46–48], preferentially depleting muscle groups of interest may benefit certain competitors; however, further evidence is required to determine the effects on physique sport performance.

If feasible, it may be ideal for competitors to achieve the required level of conditioning three to four weeks prior to competition and slowly increase CHO intake. Such an approach might improve RT performance [146] while allowing time to adjust intakes based on physique changes (i.e., increasing CHO as much as possible without increasing ST). This approach may preclude the necessity of “last minute” or otherwise harmful, drastic nutritional changes such as dehydration or sodium restriction with potassium supplementation. Contrarily, consuming a concentrated bolus of sodium immediately prior to competition in conjunction with a pump-up routine may acutely enhance appearance in relevant divisions; nevertheless, this approach is speculative (as are many assertions in this area about best practice) and requires specific study.

2.5 Conclusions

Despite the extent of its effect on physique performance being largely unexplored, CHO manipulation strategies are widely employed by physique athletes [30]. Only one quasi-experimental trial, one limited experimental trial, and few observational studies have examined CHO loading in physique athletes – highlighting a need for further, well designed studies of the topic. Accordingly, experimental designs which closely mimic the nutritional and training practices of bodybuilders and the physiological conditions they are in during PW will help both practitioners and athletes implement appropriate peaking strategies to maximise physique sport performance. Notably, ideal peaking protocols may differ per many factors that are not yet well-explored in the literature, including competitor division as well as specific performance enhancing drug-use (or lack thereof). As recruitment of physique competitors is understandably difficult [31], further quasi-experimental designs comparing more diverse samples of physique athletes who utilise different strategies may be a feasible alternative to elucidate the interactions of these variables on physique sport performance.

Chapter 3: An Examination of the Associations Between Nutritional Peaking Strategies in Physique Sport and Competitor Characteristics

Preface

The previous Chapter identified many of the limitations in the small body of research related to peaking for physique sport. Specifically, in the only relevant experimental design on the topic, the protocol implemented likely did not represent the real-world practices of competitors. Further, only two cross-sectional studies have investigated the peaking practices of competitors. Moreover, these studies captured relatively small and homogenous samples which limits their utility in informing future research designs. To address this research gap, a survey was developed and distributed to evaluate the peaking practices of a broader segment of physique athletes. This chapter specifically contributes to fulfilling thesis aim 2 by investigating the nutritional peaking strategies and how their implementation is influenced by competitor characteristics (i.e., sex, division of competition, and drug-use status). This encompassed CHO and non-CHO strategies, the length of the peaking strategy, and the difference between the highest and lowest daily CHO intakes during PW. Such evidence is important to determine the current nutritional peaking practices across different competitors which can only help develop future experimental designs in this area with greater ecological validity.

This Chapter is in preparation for submission to the *Journal of the International Society of Sports Nutrition.*

3.1 Introduction

Physique sport involves the subjective judging of competitors on variables such as muscle size, symmetry, and body fat levels which are presented through posing [149]. Competition preparation refers to the pre-contest period, where prolonged energy restriction and training manipulations are implemented by competitors to best fulfil the judging criteria of their division [1, 4]. To this end, physique athletes acutely manipulate their nutrition and training in the week prior to competition, which is colloquially known as PW [1, 4]. During PW, some athletes attempt to acutely enhance muscle size and definition by increasing intramuscular glycogen and its associated water while minimizing subcutaneous layer thickness by manipulating CHO intake, electrolytes, and water. Whilst expanding, the body of scientific evidence regarding these practices remain limited.

Despite little experimental evidence supporting their efficacy, PW strategies are common and have been documented in single-subject case studies [5, 23, 59, 100, 101], group-level observational studies [31, 55, 102], and compared in a quasi-experimental design [56]. Further, nutritional PW practices of physique athletes have been described in larger samples with cross-sectional data. Specifically, Chappell and Simper [30] reported that some form of CHO manipulation was practiced by 91% of their sample of 81 drug-free (i.e., natural) British bodybuilders, with restriction typically followed by loading to induce muscle glycogen supercompensation. Additionally, both water loading and subsequent restriction was implemented by 25% of respondents, and sodium loading by 18.5%. Qualitative interviews of experienced, high-level male bodybuilders conducted by Mitchell et al. [24] revealed that CHO loading strategies were adopted by six of the seven participants. More recently, in a survey of 29 physique athletes, the majority reported implementing CHO and water manipulation; however, the strategies as well as the reported macronutrient and water intakes were highly varied [34]. To further complicate interpretation, participants were participating in competitions where PEDs, such as anabolic-androgenic steroids (AAS), are not tested for. Competitors who use PEDs (commonly referred to as being “enhanced”) are prevalent in such competitions [21, 69, 150], and the profound physiological effects of PED-use plausibly impacts the outcomes of nutritional PW strategies. Therefore, competitor characteristics, such as drug-use status, must be considered in analyses and when interpreting outcomes.

While existing cross-sectional examinations hint to the prevalence of nutritional peaking strategies, small and homogenous samples limit the certainty of any reported associations and subsequent conclusions. Sampling from a broader population of physique athletes with the exploration of factors such as age, sex, and drug-use status, should bolster the growing understanding of nutritional PW strategies. The aim of this research was to explore relationships between competitor characteristics and (1) peaking strategy implemented, (2) length of strategies, and (3) range of daily CHO intakes during PW.

3.2 Materials and Methods

3.2.1 *Design*

This research employed a cross-sectional survey to capture the dietary and training practices of physique athletes during PW (although the present study focuses solely on dietary practices), with all questions relating to their last competition. An anonymous survey developed using Qualtrics (Qualtrics, Provo, UT) was distributed via social media. The first draft of the survey was developed by KAH in consultation with MRC and ERH. Subsequent drafts of the survey were piloted by ERH who is both a professional bodybuilder and a research fellow. Feedback from the piloting was used to modify the wording of certain questions and to add or remove questions altogether. The survey was available from August to October 2022. The outcome data were used to characterise the specific nutrition practices of physique athletes during PW, including their employed peaking strategies.

3.2.2 *Participants*

160 physique athletes (110 males, 50 females) completed the nutrition section of the survey (see Table 3-1 Sample characteristics.). All participants were made aware of the research aims and methods through the participant information sheet at the beginning of the survey and acknowledged that by taking the survey they were providing informed consent. All participants were required to be aged 18 years or older and have competed in at least one physique competition in the last five years. While the education level of the participants was not obtained, the survey employed terminology familiar to competitive physique athletes, as well as providing full definitions of terms where appropriate. This research was approved by the Auckland University of Technology Ethics Committee (AUTEC reference number 22/208).

Table 3-1 Sample characteristics.

Variable (N=160)	**Frequency**	**Percentage/Mean±*SD***
Age (years)		
18-23	22	13.8%
24-39	114	71.2%
40-49	16	10%
50-59	8	5%
Sex		
Male	110	68.8%
Female	50	31.2%
Drug Status		
Natural	104	65%
Enhanced	56	35%
Competitor Level		
Amateur	144	90%
Professional	16	10%
Competitor Division		
Men's Bodybuilding	57	39.3%
Classic Physique	18	12.4%
Men's Physique	26	17.9%
Bikini	25	17.2%
Other Women's Combined	19	13.1%
Missing/undisclosed	15	9.4%
Competition Preparation Length	160	20.35±8.03 weeks
Competition BM	160	72.09±15.74kg
ΔBM	160	11.5±5.56kg
Highest PW Daily CHO Intake (Relative)	91	425.9±225.2g (5.9±2.9g/kg)
Lowest PW Daily CHO Intake (Relative)	91	133.1±137.3g (1.9±2g/kg)

Note. SD = standard deviation, Natural = PED-free competitor, Enhanced = competitor using PED(s), BM = body mass, ΔBM = change in body mass during competition preparation, PW = peak week, CHO = carbohydrate.

3.2.3 *Procedures*

The 58-item survey (available in the supplementary material) was divided into competitor information, nutrition, and training sections. All questions were relevant to the respondent's most recent competition. The competitor information section served to gather descriptive participant data including age, sex, drug-use status (either natural or enhanced, defined as not using or using PEDs including AAS, prescription diuretics, growth hormone, insulin, fat loss agents such as clenbuterol or dinitrophenol, or any other substance banned by their respective bodybuilding federation in the case of tested competitors, respectively), competitor level (amateur or professional) and division (e.g., men's bodybuilding, bikini), competition preparation length, change in body mass during competition preparation (ΔBM), and competition body mass (BM). Questions in the nutrition section were presented in the following order: peaking strategies utilised, macronutrient and micronutrient intakes and food sources during PW, competition preparation energy and CHO intakes not during PW, and competition day strategies. Competitor descriptives, peaking strategies, and PW CHO intakes were analysed for this paper.

3.2.4 *Data Acquisition and Preparation*

All questions were designed to maintain the anonymity of participants, and no identifying information were present in the Qualtrics output. Data were initially screened for insufficiently complete and unambiguously false responses. Incomplete responses were determined by an incomplete competitor information section, while any missing data from the nutrition section was omitted. All adequate responses to the nutrition section were then organised and coded for analysis.

As the outcome variables of interest, responses to each peaking strategy (i.e., whether the strategy was implemented or not) were coded as binary outcomes for subsequent analyses. The CHO-based peaking strategies examined were back loading, mid loading, front loading, linear loading, and restriction, while non-CHO strategies were fat loading, water loading, water restriction, sodium loading, sodium restriction, and potassium loading. These variables are defined in the supplementary material. In addition to selecting the peaking strategy that competitors implemented, an option to qualitatively describe the strategy was also presented. Responses to peaking strategy length were treated as ordinal values, while the highest and lowest daily CHO intakes were extracted to make within-subject comparisons of daily PW CHO intake ranges. Relative CHO intake was determined by dividing the absolute values by competition BM.

The categorical predictors for all models were age group, sex, level, and drug-use status. The 24-39 age group, male, amateur, and natural competitors were set as the reference groups for each corresponding variable. These groups were selected as they had the largest N relative to other groups. The other levels of age consisted of 18-23, 40-49, and 50-59-years. Additionally, competition preparation length (weeks), competition BM (kg), and ΔBM (kg) were included as continuous predictors. For competitor division, all non-bikini female competitors were combined to be its own group due to the dispersion of responses across similar divisions.

3.2.5 *Statistical Analysis*

All statistical analyses were performed in R language and environment for statistical computing [151] using the *FactoMinerR* [152], *lme4* [153], and *emmeans* [154] packages, with the *performance* [155] package used to assess model diagnostics. MCA plots were produced using the *factoextra* [156] and *ggplot2* [157] packages. The supplementary files, dataset analysed, and the R scripts which detail model specifications and diagnostics are available at the Open Science Framework repository (https://osf.io/9ghfz/).

Frequencies and percentages were obtained for categorical competitor descriptives, peaking strategies, and length of peaking strategy, while means and standard deviations were calculated for competition preparation length, competition BM, ΔBM, and highest and lowest daily CHO intakes during PW.

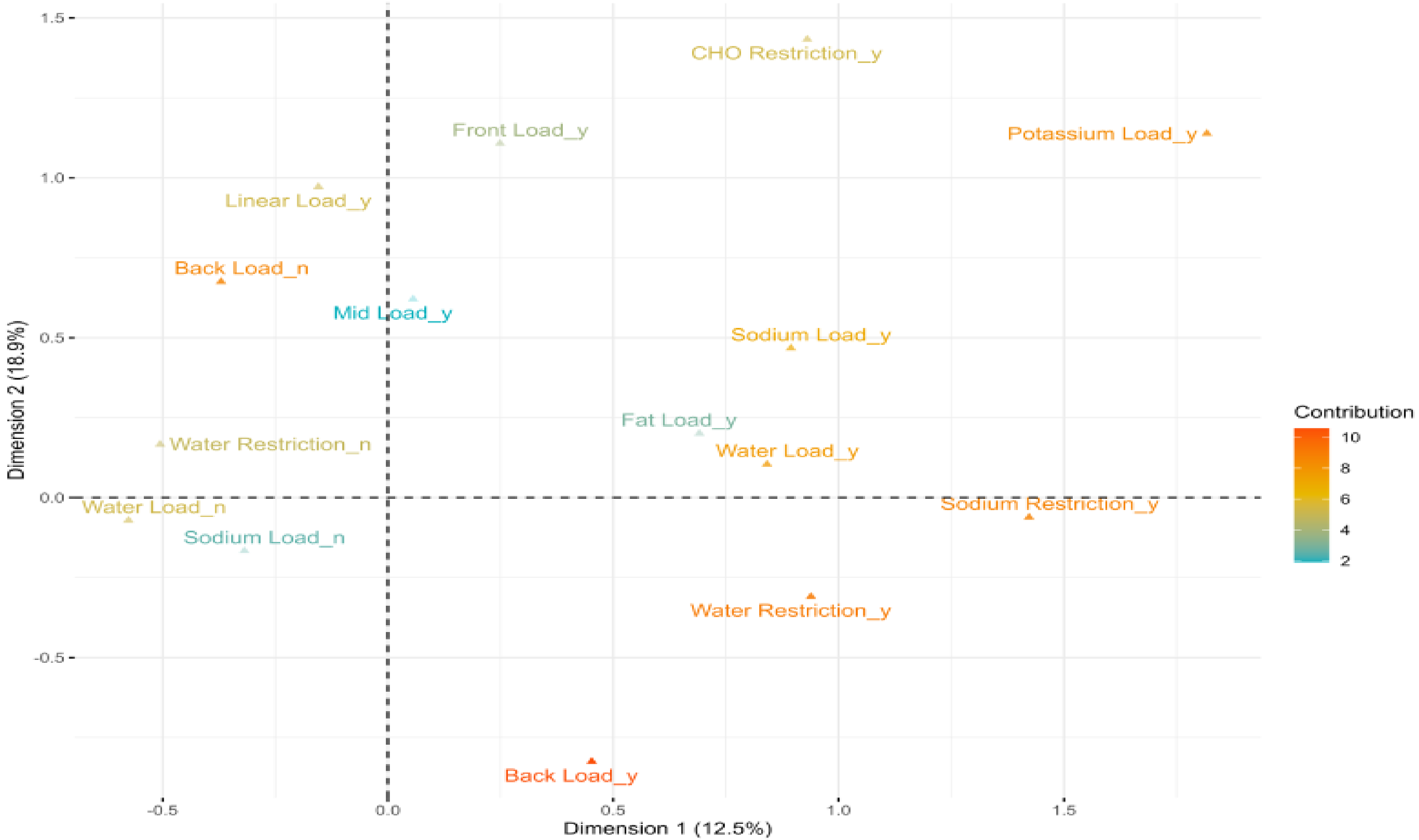
To fulfil our first research aim, a series of multiple logistic regression analyses was conducted to explore relationships between each peaking strategy utilised and participant demographics. Predictors included the categorical variables described previously, and competition preparation length and ΔBM. Model fit was assessed using likelihood ratio tests (LRT), Akaike Information Criterion score (AIC), Tjur's coefficient of determination (R^2), and binned residual plots with all reductions to the structure of the models made on theoretical grounds to obtain the best fit while satisfying assumptions and maintaining model parsimony. Within each multiple logistic regression model, odds ratios with 95% CI for each predictor variable are presented.

To address our second research aim and provide further context on the specifics of peaking strategies, multiple ordinal logistic regression was conducted to discern any relationships between competitor characteristics and peaking strategy length. The Brant-Wald test was used to assess the parallel regression assumption and reduce the model structure in conjunction with AIC, deviance statistic and LRT to obtain best fit while satisfying assumptions. For each of the predictor variables within the multiple ordinal logistic regression model, odds ratios and 95% CIs were calculated.

Linear mixed effects models were used to examine the relationship between the highest and lowest daily CHO intakes (both absolute and relative to BM) during PW and all predictors described previously. For both models, participants were treated as random effects to control for the general variation and non-independence of data. Restricted maximum likelihood estimation was used to determine both fixed and random effect regression parameters (β). The best model fit, and the contribution of all effects were obtained by comparing all explored models using the LRT, AIC, and deviance statistic. The statistical significance of predictor variables was derived using t-tests based on the Satterthwaite approximation, and the Holm-Bonferroni correction was applied post-hoc to the categorical variable age as it contained more than two levels. β with 95% CI are presented for both linear mixed models. An α level of .05 was set for all regression models and LRTs.

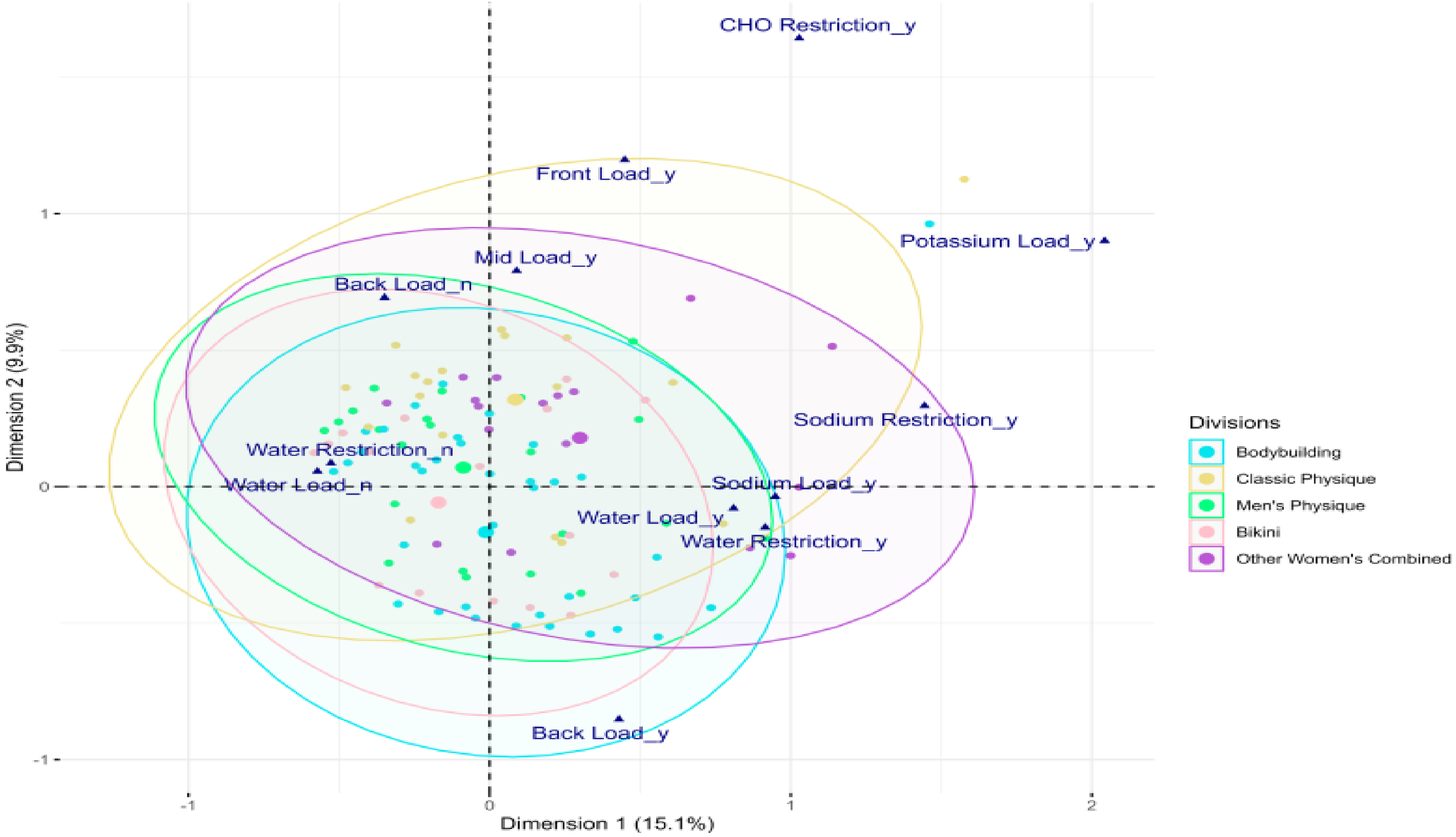
Competitor division was excluded from the multiple logistic regression analysis due to high multicollinearity, and thus its effect on PW strategies was unexplored. Therefore, to better address our first research aim, multiple correspondence analysis (MCA) with division included as a categorical variable was developed post-hoc to explore patterns in the distribution of each. MCA plots were created, but not statistically analysed due to inadequate sample size. The associated visualisations (Figure 3-1 Peaking strategy multiple correspondence analysis factor plot. and Figure 3-2 Peaking strategy multiple correspondence analysis factor biplot with competitor division.) provide additional information on the structure of our data and aid in understanding potential associations between competitor division and peaking strategies.

Figure 3-1 Peaking strategy multiple correspondence analysis factor plot.



Note. Strategies are represented as points in a Euclidean space to visualise associations. Strategies near each other are positively associated (i.e., more likely implemented in conjunction) while strategies in opposing quadrants are negatively associated (i.e., not implemented together). Points further away from the origin are more influential (i.e., had a greater proportion of responses). _y denotes the implementation of the peaking strategy while _n denotes that the peaking strategy was not implemented . Dimensions 1 and 2 explain 31.4% of total variation in the data.

Figure 3-2 Peaking strategy multiple correspondence analysis factor biplot with competitor division.



Note. Strategies and individual data points are represented in a Euclidean space to visualise associations. Strategies near each other are positively associated, while strategies in opposing quadrants are negatively associated. Strategies further away from the origin are more influential. _y denotes the implementation of the peaking strategy while _n denotes that the peaking strategy was not implemented. 95% concentration ellipses which characterise the two-dimensional distribution of each competitor division are presented (larger ellipses indicate greater variance within the division). Strategies within the concentration ellipses indicate that the strategy was strongly associated with competitors in the corresponding division. Overlap in the concentration ellipses indicate a relatively homogenous approach to peaking strategies across divisions. Dimensions 1 and 2 explain 25% of total variation in the data.

3.3 Results

3.3.1 *Sample Characteristics*

Of the 160 responses to the nutrition section of the survey, the proportion of males (68.8%) was greater than females (31.2%). For the other categorical descriptives of the survey, more natural competitors (65%) responded to the survey than enhanced (35%) and more amateur (90%) than professional (10%). For descriptors with more than two levels, ages 24-39 years (71.2%) and men's bodybuilding (39.3%) made up the highest proportion of respondents. Mean competition preparation length was 20.35±8.03 weeks, ΔBM was 11.50±5.56kg, and mean competition BM was 72.09±15.74kg. Finally, the highest and lowest daily CHO intakes during PW were 425.9±225.2g (5.9±2.9g/kg relative to BM) and 133.1±137.3g (1.9±2g/kg), respectively. The characteristics of our sample are summarised in Table 3-1 Sample characteristics..

From the peaking strategies, CHO back loading (45%), water restriction (40.6%), and water loading (40.6%) were the most utilised while CHO restriction (6.9%), potassium loading (6.9%) and CHO front loading (11%) were the least prevalent. For length of peaking strategy, starting seven days before competition was most popular (27.2%), whereas no competitor started their strategy exactly 13 days before competition (Table 3-2 Frequencies of peaking strategies utilised and peaking strategy length.).

Table 3-2 Frequencies of peaking strategies utilised and peaking strategy length.

Peaking Strategy	**N**	**Percentage**	**Peaking Strategy Length (days)**	**N**	**Percentage**
No Strategy	12	7.5%	1	4	2.7%
CHO Back Load	72	45%	2	7	4.8%
CHO Mid Load	30	18.8%	3	6	4.1%
CHO Front Load	18	11.2%	4	6	4.1%
CHO Linear Load	33	20.6%	5	22	15%
CHO Restriction	11	6.9%	6	20	13.6%
Fat Load	34	21.2%	7	40	27.2%
Water Load	65	40.6%	8	16	10.9%
Water Restriction	56	35%	9	1	0.7%
Sodium Load	42	26.2%	10	9	6.1%
Sodium Restriction	26	16.2%	11	1	0.7%
Potassium Load	11	6.9%	12	2	1.4%
Other	8	5%	13	0	0%
			14	13	8.8%

Note. CHO = Carbohydrate. All definitions of each peaking strategy are presented in the supplementary material.

3.3.2 *Associations Between Peaking Strategies Utilised and Sample Characteristics*

When examining the association between peaking strategy implemented and competitor characteristics, only water restriction (χ^2=16.07, df=9, p<.05) and sodium loading (χ^2=15.92, df=9, p<.05) were significant and explained 9.3 and 10.3% variance in the outcome variables, respectively. Being an enhanced competitor was a significant predictor for restricting water in comparison to being a natural competitor (OR=2.49 [1.17, 5.38], p<.05), while males (OR=2.99 [1.19, 8.14], p<.05) and professionals (OR=4.42 [1.19, 17.97], p<.05) had higher odds of loading sodium than their female and amateur counterparts, respectively. All results for the multiple logistic regression models for the CHO-based strategies are shown in Table 3-3 Factors affecting the implementation of carbohydrate-based peaking strategies.. Table 3-4 Factors affecting the implementation of non-carbohydrate-based peaking strategies. displays all other strategies.

Table 3-3 Factors affecting the implementation of carbohydrate-based peaking strategies.

Predictors	**Back Load**		**Mid Load**		**Front Load**		**Linear Load**		**CHO Restriction**	
	Odds Ratios (95% CI)	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*
(Intercept)	1.32 (0.41, 4.3)	.646	0.06 (0.01, 0.35)	**<.001**	0.08 (0.01, 0.51)	**.01**	0.45 (0.1, 1.87)	.276	0.63 (0.07, 5.16)	.669
Age [18-23]	0.78 (0.29, 2.04)	.616	1.44 (0.41, 4.46)	.54	0.9 (0.13, 3.93)	.898	0.16 (0.001, 0.87)	.087	1.37 (0.18, 7.25)	.726
Age [40-49]	0.83 (0.18, 3.75)	.811	0.8 (0.14, 3.3)	.769	1.57 (0.28, 6.83)	.572	1.03 (0.24, 3.69)	.97		
Age [50-59]	1.29 (0.24, 7.04)	.767	0.6 (0.03, 3.88)	.648			1.02 (0.14, 4.92)	.986	1.89 (0.09, 14.38)	.59
Sex [Female]	0.74 (0.34, 1.57)	.433	0.76 (0.27, 2.01)	.594	0.98 (0.27, 3.22)	.969	0.87 (0.35, 2.09)	.753	0.95 (0.2, 3.99)	.95
Level [Professional]	0.44 (0.11, 1.5)	.211	1.65 (0.37, 6.53)	.487	2.11 (0.37, 9.76)	.36	0.94 (0.22, 3.34)	.932	1.26 (0.06, 10.23)	.848
Drug Status [Enhanced]	1.56 (0.76, 3.22)	.266	1.57 (0.62, 3.95)	.34	1.98 (0.66, 5.91)	.215	0.76 (0.3, 3.34)	.545	0.61 (0.11, 2.56)	.516
Competition Preparation Length (weeks)	1 (0.96, 1.04)	.986	1.07 (1.01, 1.13)	**.025**	1.05 (0.91, 1.05)	.606	1.02 (0.97, 1.08)	.393	0.96 (0.86, 1.04)	.36
ΔBody Mass (kgs)	0.97 (0.9, 1.03)	.321	1.01 (0.93, 1.1)	.743	1.02 (0.94, 1.15)	.422	0.94 (0.85, 1.02)	.139	0.89 (0.76, 1.03)	.128
Likelihood Ratio Test	χ^2 df		χ^2 df		χ^2 df		χ^2 df		χ^2 df	
p<.05 indicates significant difference from null model	7.17 9	.518	7.59 9	.475	4.12 8	.766	6.67 8	.464	3.45 8	.84
Tjur's R^2	.044		.05		.023		.042		.042	
Binned Residuals *>95% indicates good model fit*	100%		92%		67%		92%		50%	

Note. CI = confidence interval, ΔBody Mass = change in body mass during competition preparation, Likelihood Ratio Test = assessment of model fit in comparison to the null model, χ^2 = chi-squared statistic, df = degrees of freedom, Tjur's R^2 = Tjur's coefficient of determination/discrimination, assessment of model predictive power, Binned Residuals = assessment of model fit. Odds ratios and p-values for the variable in square brackets are calculated in comparison to the corresponding reference group. Bold text denotes statistical significance.

Table 3-4 Factors affecting the implementation of non-carbohydrate-based peaking strategies.

Predictors	**Fat Load**		**Water Load**		**Water Restriction**		**Sodium Load**		**Sodium Restriction**		**Potassium Load**	
	Odds Ratios (95% CI)	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*
(Intercept)	0.59 (0.14, 2.43)	.464	0.54 (0.15, 1.86)	.331	0.65 (0.19, 2.26)	.501	0.23 (0.05, 0.9)	**.038**	0.07 (0.01, 0.36)	**.002**	0.08 (0.01, 0.7)	**.031**
Age [18-23]	0.4 (0.06, 1.59)	.25	1.78 (0.66, 4.78)	.25	2.17 (0.8, 5.97)	.127	0.66 (0.17, 2.08)	.507	1.83 (0.45, 6.42)	.358	0.87 (0.04, 5.82)	.903
Age [40-49]	1.54 (0.36, 5.73)	.531	0.63 (0.17, 2.08)	.459	0.64 (0.29, 3.81)	.897	0.29 (0.05, 1.27)	.133	0.71 (0.1, 3.39)	.699	0.62 (0.03, 4.57)	.689
Age [50-59]	2.12 (0.4, 9.72)	.34			0.64 (0.09, 3.19)	.615	1.58 (0.3, 7.17)	.558	0.77 (0.04, 5.03)	.815		
Sex [Female]	1.22 (0.49, 3)	.667	1.55 (0.71, 3.41)	.269	2.04 (0.9, 4.69)	.088	0.33 (0.12, 0.84)	**.026**	3.67 (1.36, 10.39)	**.011**	1.72 (0.42, 6.84)	.435
Level [Professional]	0.42 (0.06, 1.88)	.309	0.81 (0.22, 2.72)	.734	0.47 (0.09, 1.81)	.306	4.42 (1.19, 17.97)	**.029**	0.3 (0.01, 2.02)	.297	0.82 (0.04, 6.45)	.869
Drug Status [Enhanced]	1.6 (0.67, 3.78)	.283	1.9 (0.9, 4.08)	.095	2.49 (1.17, 5.38)	**.019**	1.98 (0.87, 4.57)	.106	3.09 (1.16, 8.56)	**.025**	2.88 (0.74, 11.79)	.125
Competition Preparation Length (weeks)	0.97 (0.92, 1.03)	.357	1.02 (0.97, 1.07)	.469	0.96 (0.91, 1.01)	.122	1.05 (0.99, 1.1)	.079	1.01 (0.95, 1.08)	.702	1.02 (0.93, 1.12)	.641
ΔBM (kgs)	0.96 (0.88, 1.04)	.343	0.95 (0.88, 1.02)	.157	1 (0.93, 1.07)	.967	0.96 (0.89, 1.03)	.255	0.98 (0.9, 1.07)	.729	0.91 (0.79, 1.03)	.146
Likelihood Ratio Test	χ^2 df		χ^2 df		χ^2 df		χ^2 df		χ^2 df		χ^2 df	
p<.05 indicates significant difference from null model	9.9 9	.272	7.51 8	.377	16.07 9	**.041**	15.92 9	**.044**	12.59 9	.127	5.79 8	.564
Tjur's R^2	.065		.048		.093		.103		.088		.038	
Binned Residuals *>95% indicates good model fit*	100%		92%		92%		100%		77%		58%	

Note. CI = confidence interval, ΔBM = change in body mass during competition preparation, Likelihood Ratio Test = assessment of model fit in comparison to the null model, χ^2 = chi-squared statistic, df = degrees of freedom, Tjur's R^2 = Tjur's coefficient of determination/discrimination, assessment of model predictive power, Binned Residuals = assessment of model fit. Odds ratios and p-values for the variable in square brackets are calculated in comparison to the corresponding reference group. Bold text denotes statistical significance.

There was no significant relationship between the included predictor variables and peaking strategy length (χ^2=2.35, df=3, p>.05). The models examining factors influencing daily CHO intake ranges during PW (Table 3-5 Factors affecting the (1) the absolute difference between the lowest and highest daily carbohydrate intake during peak week; (2) the relative difference between the lowest and highest daily carbohydrate intake during peak week; and (3) peaking strategy length) explained 58.2 and 62.4% of the variance in absolute and relative differences, respectively. Sex was the only significant predictor for PW CHO intake, where the disparity between the lowest and highest PW CHO intakes was smaller in females compared to males for absolute intake (β=-108.8 [-216.3, -1.2], p<.05). When CHO intake was relative to BM, again, only the effect of sex was significant (β=-1.7 [-3.2, -0.2], p<.05).

Table 3-5 Factors affecting the (1) the absolute difference between the lowest and highest daily carbohydrate intake during peak week; (2) the relative difference between the lowest and highest daily carbohydrate intake during peak week; and (3) peaking strategy length.

Predictors	**Factors Affecting Absolute CHO Difference**		**Factors Affecting Relative CHO Difference**		**Factors Affecting Peaking Strategy Length**	
	β (95% CI)	*p*	*β (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*
(Intercept)	273.4 (59.9, 486.8)	**.012**	9.7 (5.7, 13.7)	**<.001**		
CHO Intake [Lowest]	-292.8 (-338.5, -247.1)	**<.001**	-3.9 (-4.6, -3.4)	**<.001**		
Age [18-23]	12 (-85.4, 109.4)	.808	0.2 (-1.2, 1.6)	.805		
Age [40-49]	38.9 (-65.4, 143.1)	.463	0.6 (-0.9, 2.1)	.447		
Age [50-59]	-23.9 (-152.5, 104.6)	.713	-0.4 (-2.2, 1.5)	.692		
Sex [Female]	-108.8 (-216.3, -1.2)	**.047**	-1.7 (-3.2, -0.2)	**.031**	0.9 (0.5, 1.8)	.803
Level [Professional]	-5.8 (-107.7, 96)	.911	-0.3 (-1.7, 1.2)	.691		
Drug Status [Enhanced]	-69.7 (-148.7, 9.18)	.083	-1 (-2.1, 0.1)	.075	0.6 (0.3, 1.2)	.131
Contest Preparation Length (weeks)	-1.1 (-5.2, 3)	.602	-0.02 (-0.1, 0.04)	.454		
ΔBM (kg)	5.57 (-0.14, 11.3)	.056	0.1 (-0.02, 0.2)	.110	0.99 (0.9, 1.1)	.813
Competition Body Mass (kg)	0.8 (-2.7, 4.2)	.665	-0.04 (-0.09, 0)	.072		

Random Effects					
σ^2	24344.85	3.98			
$\tau_{00 \text{ Participant}}$	6943.45	1.85			
ICC	.22	.32			
N	91	91		147	
Observations	182	182		147	
Likelihood Ratio Test			χ^2	df	
p<.05 indicates significant difference from null model			2.35	3	.504
Marginal R^2 / Conditional R^2	.463 / .582	.449 / .624			
R^2 Nagelkerke				.016	

Note. CHO = carbohydrate, β = regression parameter estimate of fixed effects, CI = confidence interval, ΔBody Mass = change in body mass during competition preparation, σ^2 = variance of error, $\tau_{00 \text{ Participant}}$ = random effects of participants, ICC = Intraclass correlation coefficient, random effects: total variance ratio, Likelihood Ratio Test = assessment of model fit in comparison to the null model, χ^2 = chi-squared statistic, df = degrees of freedom, R^2 = coefficient of determination, Marginal R^2 = proportion of variance from fixed effects, Conditional R^2 = proportion of variance from both fixed and random effects, R^2 Nagelkerke = proportion of variance explained in comparison to the null model. β/odds ratios and p-values for the variable in square brackets are calculated in comparison to the corresponding reference group. Bold text denotes statistical significance.

3.4 Discussion

The aim of this study was to determine the nutritional peaking strategies implemented by physique athletes and identify relationships between strategies and competitor characteristics. The results of this study indicate that competitors acutely manipulate their nutrition to enhance their onstage aesthetic in accordance with previous research [24, 30, 34]. However, there was no association between competitor characteristics and peaking strategy length and the implementation of CHO-based strategies, while only water restriction and sodium load models were significant among the non-CHO based strategies. Enhanced competitors were more likely to restrict water than natural, while sodium loading was more likely to be practiced by males and professionals in comparison to females and amateurs, respectively. Finally, sex predicted the range of daily CHO intakes during PW for both absolute and relative amounts.

CHO manipulation strategies were prevalent within our sample where CHO backloading was the most popular strategy (45%). This finding is comparable to Chappell et al. [30] who noted that within the majority of their respondents (a more homogenous sample of bodybuilders) who manipulated CHO, restriction was followed by CHO loading. However, none of the present competitor characteristics predicted the implementation of CHO-related strategies which could be due to underpowered analyses from a small sample size. The lack of predictive power of the models, which range from only 2.3-5% of the variance explained (Tjur's R^2 = .023-.05) may highlight the variability of strategies amongst competitors or indicate unmeasured variables that may better predict the implementation of these strategies. In any case, appropriately exploring the relationships at play in this area is complex and warrants further research.

Enhanced competitors are seemingly 2.5 and 3.1 times more likely to restrict water and sodium, respectively, compared to their natural counterparts. Despite the large odds ratios, these results should be interpreted with caution due to the wide confidence intervals, and the non-significant and poor overall fit of the sodium restriction model (Tjur's R^2 = .088, binned residuals = 77%, p=.127). Nonetheless, these strategies are likely implemented to minimise fluid retention, a common side effect of administering AAS [158, 159]. Interestingly, both enhanced and natural competitors have been observed to restrict water and dietary sodium [30, 134, 160]. It has also been proposed that the temporal lag following manipulation of these variables could be leveraged to clear superfluous body water before homeostasis is reestablished, thereby enhancing the appearance of muscle [2]. Despite the theoretical potential to reduce fluid retention, the efficacy and safety of these strategies are under debate, and the effects of such practices on physique sport performance have not been empirically confirmed [149]. Ultimately, until future research is conducted, it is unknown whether there are net benefits or detriments in enhanced competitors when using such strategies. Further, it is likely that an individualised and carefully balanced approach needs to be found for such strategies to prove successful.

Interestingly, professional competitors were over fourfold more likely to load sodium than amateur competitors. This result might indicate an effort to maximise the effects of a “pump-up” routine [4, 149]. While experimental evidence is required to determine the effects of increasing sodium intake before competition, it plausibly may result in acute increases in blood pressure and volume, potentially beneficial for performance in certain divisions and is a speculative recommendation in previous reviews [4, 149]. Although the magnitude of effect of sodium loading is unknown, more successful and higher-level competitors adopting this strategy may point to a degree of ergogenic effect. However, since very few professionals were sampled in this study (N=16), and previous recommendations are predicated on empirically unconfirmed physiological reasoning, these results and recommendations should be interpreted and implemented with caution.

Males were also three times more likely to load sodium than females, which may be attributed to the judging criteria of divisions such as bikini. Bikini competitors, in contrast to male bodybuilders, are required to present less extreme muscle size and definition, and vascularity [161]. Furthermore, while not significant, females had a higher likelihood of restricting water (OR=2.04 [0.9, 4.69], p=.088), and despite poor model fit, females may be more likely to restrict sodium (OR=3.67 [1.36, 10.39], p<.05). These results support the findings of Alwan et al. [162], who reported that 44% of their sampled female physique athletes manipulated sodium, and over 70% loaded and restricted water prior to competition. Accordingly, while the proportion of water loading was greater in females in our sample, the odds were non-significant (p=.269). Collectively, this may indicate that restricting water following loading is a common strategy used by female competitors to reduce subcutaneous water to enhance appearance with less concern for maintaining muscle size.

While the number of days prior to competition when peaking began was not predicted by competitor characteristics, 66.7% of strategies commenced between five and eight days prior to competition. This is in line with the recommendations of Escalante et al.

[2] and is observed in case studies of peaking competitors, where manipulations began four to six days before competition [5, 23, 59, 100]. These nutritional manipulation timeframes are similar to the traditional CHO loading protocols employed by endurance athletes [163].

Interestingly, a non-negligible number of competitors in our sample (8.8%) commenced their strategy 14 days away from competition, a value not previously observed in the literature. Post-hoc analysis of qualitative responses at this timepoint revealed that these competitors either increased energy intake slowly leading up to competition (i.e., CHO linear load), began restricting CHO severely, or sharply increased their water intake which was then restricted closer to competition. While a greater sample size and more detailed information is required to confirm why these competitors made such manipulations two weeks before competition, these responses indicate that different approaches were used. This may be due to these strategies being highly individualised and reactive, whereby competitors may have adjusted their strategy based on visual changes in appearance (i.e., muscle size and definition).

When comparing the differences between the lowest and highest daily CHO intakes during PW for competitors, sex was a significant predictor, with females having a smaller disparity in both absolute and relative values. Thus, female competitors' CHO intakes are more stable in PW compared to males who may engage in more extreme CHO manipulation strategies. This may reflect divisional differences, whereby a more extreme look is required for males and may compel them to implement depletion and loading phases. Similarly, competitors who achieved greater weight loss during contest preparation were more likely to have a greater difference between these values. This may be due to the requirements of certain divisions where competitors are required to achieve a very low level of adiposity, requiring very low energy (and thus CHO) intake, who then attempt to acutely increase muscle size through CHO loading strategies. While not formally analysed due to multicollinearity issues and sample size limitations with alternative analyses (MCA), some general trends between competition division and peaking strategies are visible. The overlap and lack of dispersion between divisions may indicate many peaking strategies are not strongly correlated with competition division. However, some relationships seemingly exist between bodybuilding and CHO back loading, and classic physique and CHO front-loading. These associations (or lack thereof) require further exploration as the displayed dimensions only account for 25% of variance in our data. Further, the association between the bodybuilding division and

CHO back loading could be explained by both variables being the most prevalent in our dataset within their respective categories (i.e., division and peaking strategy, respectively).

There are certain limitations that exist within this study. While obtaining a large sample size relative to previous surveys on PW [30, 34], a greater sample size would have improved odds ratio and β accuracy, potentially reducing type II errors, and enhancing the generalisability of the results. Additionally, a larger sample size potentially captures more competitors of different divisions, whereby the interactions between competitor division and peaking strategy could be explored further. The generalisability of the results is also likely constrained by the manner of its distribution. As the survey was mostly advertised by prominent social media exercise science communicators, it is likely that the approaches of the participants may be strongly influenced by who they follow on social media. While effort was made for the survey to be advertised by a range of social media users, this may have led to the survey only capturing a certain segment of competitors. Finally, as the number of eligible competitors who were not reached by or did not respond to the survey is unknown, generalising the results of this survey is difficult.

This was a large survey with many questions where 160 participants completed the nutrition section of the survey; however, only 104 completed the survey in full. This may hold implications on the validity of the responses in addition to common issues with surveys (biased or incomplete recollections, mostly true responses with some fabricated details, or entirely false responses) [21]. To counteract these limitations, the participants were informed that the survey was anonymous before commencing which may have reduced deliberate false responses. Further, responses were screened for unambiguously false entries to minimise inaccuracies and false information. Based on our low completion rate, we recommend future researchers build on our findings with more targeted approaches. Using a simpler but concentrated survey to increase the number of responses on more specific topics might be reasonable trade-off for a less encompassing view of PW strategies.

It is important to acknowledge the inherent variability of peaking strategies, as the sheer number of interrelated variables makes it difficult to capture all aspects of PW with robust models. Nevertheless, exploring other variables that may predict PW strategies is a valuable avenue of investigation. Finally, while this survey captured both nutrition and training variables during PW, their interactions were not evaluated for the purpose of this study and requires further exploration.

3.5 Conclusion

The relationships between competitor characteristics and nutritional PW strategies were examined with a series of regression models. No significant predictors were found for CHO-based PW strategies, as well as PW strategy length. In comparison to females, males were more likely to load sodium and have greater differences between their highest and lowest PW CHO intakes, and while not significant, females had a higher likelihood of restricting water. Enhanced competitors were more likely to restrict water than their natural counterparts and professional competitors more likely to load sodium than amateurs. Finally, as competitor division could not be included in any of the regression models, MCA plots are available to the reader to visualise the associations between each division and nutritional PW strategies. This study provides further insight on the relationship between physique athlete characteristics and their nutritional peaking strategies which display high degrees of complexity and individualisation. Nevertheless, our results should be interpreted and generalised with caution, accounting for the limitations of online surveys and pending future work with larger samples allowing more confident assertions.

Chapter 4: A Survey of Resistance Training Practices Among Physique Competitors During Peak Week

Preface

The lack of cross-sectional studies concerning the peaking strategies of physique athletes was highlighted in Chapter 2. Further, these studies did not examine the RT practices of competitors during PW. Thus, there is an empirical gap in the understanding of competitors' RT manipulations before competition. Notably, the only experimental PW study implemented a RT protocol which did not replicate the practices of competitors and thus would plausibly affect the efficacy of the examined nutritional strategy. Therefore, using data from the same survey from the previous Chapter, the relationship between competitor characteristics and the manipulation of RT variables was examined. Additionally, the degree of change in the manipulated variables were determined by comparing PW with the WBPW. Making such comparisons gives rise to the development of new hypotheses regarding the rationale of RT PW strategies and how they may interact with nutritional strategies, as explored in Chapter 3. In summary, this Chapter investigated the influence of competitor characteristics on RT variable manipulation as well as the magnitude of these changes, thereby contributing to the fulfilment of thesis aim 2. These findings provide a more global understanding of the peaking practices of competitors which can inform both future research designs and the practice of coaches and competitors.

This Chapter is in preparation for submission to the *Journal of Strength and Conditioning Research.*

4.1 Introduction

Physique sport competitors are subjectively judged in competition based on the presentation of variables such as body fat levels, muscle size, and symmetry, through posing [149]. During the pre-contest period, competitors look to fulfil the judging criteria of their respective division by reducing body fat levels and enhancing muscle through training and nutrition regimens [1, 2, 4]. To further affect these variables, many competitors will explicitly manipulate their behaviours in the week before competition. This is commonly referred to as "PW". While nutritional strategies of physique competitors during this period are well documented [24, 30], PW RT practices are largely unexplored.

From their recent PW recommendations for bodybuilders, Escalante and colleagues [2] propose the manipulation of RT to enhance nutritional strategies such as CHO loading. The rationale behind these recommendations is to deplete muscle glycogen while minimising muscle damage to maximise muscle glycogen storage during CHO loading [2]. Such strategies are commonly implemented to enhance muscle size and thus, performance [30]. Nevertheless, the interaction between RT and nutritional peaking strategies are unknown, highlighting the need for a greater understanding of the current practices of competitors to inform future experimental research.

While detail regarding specific RT manipulations during PW have not been reported, the general RT practices of male bodybuilders are seemingly homogeneous in the pre-competition period, where the majority of competitors train with high frequencies, and moderate-to-high loads and repetitions [21, 69, 150]. High training frequency and repetitions were also observed within a survey of males and females competing in different physique sport divisions. Contrastingly, within session set volume and proximity-to-failure of exercises varied within the same sample [34], perhaps owing to the recruitment of a wider population of physique athletes.

It is conceivable that training practices vary based on competitor characteristics, where factors like sex, drug-use status, division of competition, and competition preparation length may relate to which RT variables are manipulated during PW and how. Further, making detailed comparisons between the week before PW (WBPW) and PW for each RT variable would allow for inferences and further hypotheses to be made regarding the magnitude and directionality of such changes. Such findings could help develop ecologically valid RT protocols for future experimental research investigating peaking strategies.

While RT practices of physique athletes in the pre-competition period (which encompasses PW) have been previously described in the literature, results are reported without any delineation for PW [21, 69, 150]. Consequently, specific detail during PW and its associations with competitor characteristics are currently limited. Therefore, the aims of this research were to assess the relationship between competitor characteristics (i.e., sex and drug-use status) and specific RT variables manipulated during PW, as well as determining the magnitude of change in these variables in comparison to WBPW. To this end, a survey was designed and distributed to collect more detailed information on RT variables during PW. No hypotheses were made for this research as it was an exploratory first step to better understand RT practices across a broad segment of physique athletes and to guide future experimental designs examining peaking strategies.

4.2 Methods

4.2.1 *Experimental Approach to the Problem*

A 58-item survey developed using Qualtrics (Qualtrics, Provo, UT) was distributed via social media to assess the training and nutritional practices of physique athletes during PW of their most recent competition. The survey was developed by the research team which contains a professional bodybuilder. The survey was distributed using social media and participants were able to complete the survey between August and October 2022. The training section of this survey encompassed the RT, cardiovascular training, and pump-up routines of the competitors during WBPW and PW. For this paper, the RT manipulations during PW as well as comparisons with the WBPW were analysed.

4.2.2 *Participants*

Physique athletes who had competed within the last five years (2017-2022) and were over the age of 18 at the time of competition were invited to complete the survey. Informed consent was obtained from each participant who read a participant information sheet detailing the research aims before starting the survey. The Auckland University of Technology Ethics Committee approved this research (AUTEC reference number 22/208).

Table 4-1 Competitor characteristics and resistance training variables manipulated.

Variable (N=104)	**Frequency**	**Percentage/Mean±*SD***
Age (years)		
18-23	10	9.6%
24-39	78	75%
40-49	11	10.6%
50-59	5	4.8%
Sex		
Male	70	67.3%
Female	34	32.7%
Drug Status		
Natural	65	62.5%
Enhanced	39	37.5%
Competitor Level		
Amateur	92	88.5%
Professional	12	11.5%
Competitor Division		
Men's Bodybuilding	36	34.6%
Classic Physique	12	11.5%
Men's Physique	12	11.5%
Bikini	16	15.4%
Other Women's Combined	15	14.4%
Missing/undisclosed	13	12.5%
Competition Preparation Length	104	17.3±9.9 weeks
ΔBM	104	10.5±5.2kg
RT Variable Manipulated		
Training Split	50	57.5%
Exercise Selection	40	46%
Frequency	32	36.8%
Number of Sets	59	67.8%
Repetition Range	46	52.9%
Load Range	51	58.6%
Proximity-to-Failure	65	74.7%

Notes. SD = standard deviation, Natural = PED-free competitor, Enhanced = competitor using PED(s), ΔBM = change in body mass during competition preparation, RT = resistance training.

4.2.3 *Procedures*

The survey consisted of competitor information, training, and nutrition segments. Participants self-reported their age group, drug-use status (either natural or enhanced, defined as not using or using performance-enhancing drugs or any other substance banned by their respective bodybuilding federation in the case of tested competitors, respectively), competitor level (amateur or professional) and division (i.e., physique, bodybuilding, bikini, etc.), competition preparation length and ΔBM. The training section assessed the resistance and cardiovascular training variables manipulated, the differences between WBPW and PW of these variables, and the pump-up routine. For this study, only competitor information and RT variables were analysed.

4.2.4 *Data Acquisition and Preparation*

The survey was distributed on social media and completed electronically. The anonymity of participants was maintained through the careful design of questions, and thus the raw output yielded no identifying information. Data were screened for incomplete and explicitly false responses following exportation (i.e., set volume values that were improbably high and/or a random combination of values). Incomplete responses were defined as those without an answer to a linchpin question regarding the selection of RT variables which were manipulated, while any missing data from the training section was omitted from the corresponding statistical analysis. Subsequently, 104 adequate responses for the training section were organised and coded for analysis.

Binary responses to the RT variables manipulated were organised as the outcome variable of interest to be predicted by subsequent statistical models. These variables were training split, training frequency, exercise selection, set volume, repetition range, load range, and proximity-to-failure (see supplementary materials for definitions).

Of the categorical variables used to predict the manipulation of RT variables, sex, level (amateur and professional), and drug-use status (natural and drug-enhanced) each contained two levels, while age contained four (18-23, 24-39, 40-49, and 50-59 years). Competitor division was organised into five levels as non-bikini female competitors were combined in its own group due to the dispersion of responses across similar divisions. Levels which contained the largest N within the corresponding variable were set as the reference group. Additionally, competition preparation length (weeks), and ΔBM (kgs) were included as continuous predictors.

To gather further detail on RT variable manipulation, participants provided specific values for WBPW and PW for only the RT variables they manipulated. For training split, participants selected the split which best described their RT for each week from the following: push/pull/legs, full body, upper/lower, body part and other. Set volume was treated as a continuous variable and defined as the number of working sets completed each week. Frequency, repetition ranges, load ranges and proximity-to-failure were considered discrete variables. Frequency was determined as the number of days RT was performed during each week, while participants selected repetition and load (as % of estimated or actual 1RM) ranges which best represented their RT from a dropdown list. Finally, the participants' estimated average proximity-to-failure for working sets was determined using a 5-10 'repetitions in reserve' (RIR) scale with increments of 0.5. The options for both repetition and load ranges as well as the descriptives attached to values on the RIR scale are presented in Table 4-5. Set volume, repetition ranges, load ranges, and proximity-to-failure were divided into upper body compound (UBC), lower body compound (LBC), upper body isolation (UBI), lower body isolation (LBI), and abdominal and back (trunk) exercises for analysis.

4.2.5 *Statistical Analysis*

All statistical analyses were conducted in R language and environment for statistical computing [151] using the *effsize* [164] and *rcompanion* [165] packages while model diagnostics were assessed using the *performance* [155] package. Data, diagnostics, and code are available at the Open Science Framework repository (https://osf.io/9ghfz/).

Participant characteristics are presented with counts and percentages for categorical variables and means and standard deviations for continuous variables. Counts and percentages are also presented for RT variables manipulated and the training splits employed. Means with standard deviations, and percentage change were calculated for set volumes, while medians are presented for training frequency, repetition range, load range, and proximity-to-failure.

To address our first research aim, a series of multiple logistic regression analyses were conducted to examine the relationship between each RT variable manipulated and competitor characteristics. Further, the continuous predictors of competition preparation length (weeks) and ΔBM (kg) were included in each model. LRT, Tjur's R^2, and binned residual plots were used to assess model goodness-of-fit. The variance inflation factor (VIF) was calculated to assess collinearity amongst predictors within each model, with competition division removed from all models as a predictor due to violating the assumption (VIF>10). Odds ratios with 95% CI are presented for each multiple logistic regression model.

Comparisons between WBPW and PW were made to ascertain the degree of change in the RT variables and fulfil our second research aim. A McNemar-Bowker test was used to detect differences in training splits between WBPW and PW for all competitors.

Paired t-tests were used to make comparisons between WBPW and PW for total, UBC, UBI, LBC, LBI, and trunk set volume changes. Mean differences and Cohen's *d* effect size (ES) with 95% CI were calculated. Normality of the differences between pairs for continuous values were checked with histograms and the Shapiro-Wilk test. A normal distribution was assumed with t-tests involving samples N>30 according to the central limit theorem [166]. Differences for UBI, LBI, and trunk sets were non-normal, and while paired t-tests are considered robust to the violations of the assumption of normality [167], p-values and ES should be interpreted with caution. Wilcoxon-signed rank tests were used to make comparisons for training frequency, repetition ranges, load ranges, and RIR where the continuity correction was applied for tests with N<20. Pseudomedians with non-parametric 95% CI were calculated, while ES (*r*) with 95% CI estimated by 1000 bootstrapped samples were also determined to aid interpretation of the Wilcoxon-signed rank tests. Paired observations were accounted for when calculating both *d* and *r* ES. For interpretation, *d* values of <0.2, 0.2-0.5, 0.5-0.8, and >0.8 were considered negligible, small, medium, and large effects, respectively. While *r* values of <.3, .3-.5, and >.5 were considered small, medium, and large effects, respectively. Significance was determined as p<.05 for all statistical analyses.

4.3 Results

4.3.1 *Sample Characteristics*

A summary of the descriptive statistics of the sample are presented in Table 4-1 Competitor characteristics and resistance training variables manipulated. From the responses to the training section of the survey, the proportion of males (67.3%) were greater than females (32.7%), and more natural competitors (62.5%) responded to the survey than enhanced (37.5%). The age group of 24-39 years (75%), amateur (88.5%) and men's bodybuilding (34.6%) had the highest proportion of respondents. Mean±*SD* competition preparation length was 17.3±9.9 weeks while ΔBM was 10.5±5.2kg.

Regarding RT variables manipulated, proximity-to-failure (74.7%) and set volume (67.8%) had the highest frequencies while exercise selection (46%) and training frequency (36.8%) had the least (Table 4-1). For training split, push/pull/legs and body part split (32.6%) were most popular during WBPW, while for PW the implementation of an upper/lower split (30.3%) was most prevalent (Table 4-2 Cross-tabulation of training split frequencies for week before peak week and peak week).

Table 4-2 Cross-tabulation of training split frequencies for week before peak week and peak week.

Training Split (N=104)	**Week Before Peak Week**		**Peak Week**	
Push/Pull/Legs	29	27.9%	8	7.7%
Full Body	4	3.8%	22	21.1%
Upper/Lower	22	21.1%	27	25.9%
Body Part	29	27.9%	22	21.1%
Other	5	4.8%	10	9.6%
Missing	15	14.4%	15	14.4%

Note. McNemar-Bowker Test: χ^2=33.06, df=9, p<.001

4.3.2 *Associations Between Resistance Training Variables Manipulated and Sample Characteristics*

None of the models were significantly different to the null according to the LRT when examining the association between the RT variables manipulated and competitor characteristics (Table 4-3 Competitor characteristics affecting the manipulation of resistance training variables).

Table 4-3 Competitor characteristics affecting the manipulation of resistance training variables.

Predictors	**Training Split**		**Training Frequency**		**Exercise Selection**		**Set Volume**		**Repetition Range**		**Load Range**		**Proximity-to-failure**	
	Odds Ratios (95% CI)	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*	*Odds Ratios (95% CI)*	*p*
(Intercept)	0.34 (0.07, 1.52)	.164	0.74 (0.18, 3.1)	.683	0.12 (0.02, 0.55)	**.009**	0.74 (0.18, 3.1)	.683	0.48 (0.11, 1.98)	.312	0.39 (0.09, 1.61)	.199	0.2 (0.04, 0.9)	**.042**
Age [18-23]	2.38 (0.58, 10.97)	.236	2.24 (0.54, 11.63)	.286	2.47 (0.58, 10.8)	.216	2.24 (0.54, 11.63)	.286	0.88 (0.2, 3.48)	.853	6.57 (1.44, 47.46)	**.027**	2.07 (0.47, 11.45)	.36
Age [40-49]	4.52 (1.01, 27.5)	.066	0.73 (0.18, 3)	.657	2.57 (0.61, 11.93)	.202	0.73 (0.18, 3)	.657	1.54 (0.2, 3.48)	.545	1.17 (0.28, 4.8)	.827	0.64 (0.14, 3.02)	.561
Age [50-59]	0.46 (0.02, 3.62)	.535	0.78 (0.09, 5.28)	.796	1.92 (0.22, 14.39)	.522	0.78 (0.09, 5.28)	.796	0.32 (0.02, 2.45)	.329	2.7 (0.4, 22.7)	.309	0.5 (0.05, 3.89)	.507
Sex [Female]	1.01 (0.38, 2.67)	.978	0.98 (0.39, 2.52)	.972	1.78 (0.68, 4.76)	.245	0.98 (0.39, 2.53)	.972	1.81 (0.72, 4.64)	.211	1 (0.39, 2.57)	.998	2.14 (0.8, 6.1)	.138
Level [Professional]	0.21 (0.04, 0.95)	.06	1.36 (0.35, 5.9)	.664	0.24 (0.04, 1.08)	.086	1.36 (0.35, 5.9)	.664	0.43 (0.09, 1.66)	.238	2.28 (0.6, 9.76)	.236	3.03 (0.64, 22.56)	.202
Drug Status [Enhanced]	1.66 (0.69, 4.12)	.341	1.09 (0.45, 2.72)	.851	1.4 (0.55, 3.65)	.484	1.09 (0.45, 2.72)	.851	1.25 (0.51, 3.08)	.627	1.11 (0.45, 2.78)	.827	1.28 (0.5, 3.44)	.613
Competition Preparation Length (weeks)	1.05 (1, 1.1)	**.019**	1.04 (1, 1.09)	.073	1.06 (1.01, 1.12)	**.018**	1.04 (1, 1.09)	.073	1.01 (0.97, 1.06)	.592	1.03 (0.98, 1.08)	.219	1.11 (1.02, 1.22)	**.028**
ΔBM (kgs)	0.98 (0.89, 1.06)	.555	0.98 (0.9, 1.06)	.58	1.02 (0.93, 1.11)	.692	0.98 (0.9, 1.06)	.58	1.01 (0.93, 1.1)	.784	1.01 (0.92, 1.09)	.904	1.04 (0.99, 1.09)	.122
Likelihood Ratio Test	*χ2* df		*χ2* df		*χ2* df		*χ2* df		*χ2* df		*χ2* df		*χ2* df	
p<.05 indicates significant difference from null model	14.45 9	.071	7.59 9	.475	11.19 9	.191	5.62 9	.69	4.93 9	.764	9.34 9	.314	13.45 9	.097
Tjur's R^2	.128		.053		.103		.053		.047		.087		.121	
Binned Residuals *>95% indicates good model fit*	100%		90%		90%		90%		90%		100%		90%	

Note. CI = confidence interval, ΔBM = change in body mass during competition preparation, Likelihood Ratio Test = assessment of model fit in comparison to the null model, χ^2 = chi-squared statistic, df = degrees of freedom, Tjur's R^2 = Tjur's coefficient of determination/discrimination, assessment of model predictive power, Binned Residuals = assessment of model fit. Bold text denotes statistical significance.

4.3.3 *Comparisons Between Week Before Peak Week and Peak Week*

Training splits between WBPW and PW were different (χ^2=33.06, df = 9, p<.001). When assessing the magnitude of difference in set volume between WBPW and PW, only changes in LBI were non-significant and small (-20.82%, *d*=0.29 [-0.11, 0.71], p>.05) and the greatest changes were in LBC (-44.86%, *d*=0.72 [0.41, 1.03], p<.001) and trunk (-54.14%, *d*=0.93 [0.55, 1.31], p<.001) exercises. All results for set volume can be found in Table 4-4 Differences in set volumes between peak week and the week before..

Table 4-4 Differences in set volumes between peak week and the week before.

	N	WBPW Mean (±*SD*)	PW Mean (±*SD*)	Percentage Change (%)	Mean Difference [95% CI]	t-statistic	Effect Size (*d*) [95% CI]	*p*
Change in Total Sets	42	52.81 (41.19)	33.81 (26.88)	-35.98	19 [10.87, 27.14]	4.72	0.48 [0.27, 0.69]	<.001
Change in UBC Sets	35	18.25 (14.18)	11.71 (10.1)	-35.84	6.54 [3.73, 9.36]	4.72	0.47 [0.26, 0.69]	<.001
Change in UBI Sets	26	19.65 (18.29)	13.61 (13.61)	-30.74	6.04 [1.91, 10.17]	3.01	0.34 [0.11, 0.57]	<.01
Change in LBC Sets	38	15.36 (10.52)	8.47 (5.91)	-44.86	6.89 [4.22, 9.57]	5.23	0.72 [0.41, 1.03]	<.001
Change in LBI Sets	26	12.92 (8.97)	10.23 (8.99)	-20.82	2.69 [-.98, 6.37]	1.51	0.29 [-0.11, 0.71]	.144
Change in Trunk Sets	18	8.22 (5.08)	3.77 (3.9)	-54.14	4.44 [2.86, 6.03]	5.92	0.93 [0.55, 1.31]	<.001

Note. WBPW = week before peak week, PW = peak week, CI = confidence interval, UBC = upper body compounds, UBI = upper body isolation, LBC = lower body compounds, LBI = lower body isolation. Effect size (d) values of <0.2, 0.2-0.5, 0.5-0.8, and >0.8 were considered negligible, small, medium, and large effects, respectively.

A large decrease in training frequency between WBPW and PW was observed (*r*=-.87 [-.9, -.81], p<.001), while only UBC (*r*=.61 [.32, .84], p<.01) and LBC (*r*=.55 [.19, .87], p<.01) were different for repetition range. All body part and exercise types for load range and proximity-to-failure had large differences between WBPW and PW. Table 4-5 Differences in frequency, repetition ranges, load ranges, and proximity-to-failure between peak week and the week before. displays the results for training frequency, repetition ranges, load ranges, and proximity-to-failure.

Table 4-5 Differences in frequency, repetition ranges, load ranges, and proximity-to-failure between peak week and the week before.

RT variable and exercise	N	WBPW Median	PW Median	Pseudo Median [95% CI]	Effect Size (*r*) [95% CI]	*p*
Frequency	28	6	4	-1.99 [-2.49, -1.5]	-.87 [-.9, -.81]	<.001
Repetition Range						
Upper Body Compounds	27	4	6	1.5 [0.5, 2]	.61 [.32, .84]	<.01
Upper Body Isolation	24	5	6	0.99 [0, 1.5]	.33 [-.05, .7]	.113
Lower Body Compounds	24	4	6	1.99 [0.5, 2.49]	.55 [.19, .87]	<.01
Lower Body Isolation	22	5	6	0.49 [-0.5, 1.49]	.15 [-.27, .55]	.489
Trunk	10	5	6	0.49 [-1, 1.99]	.21 [-.41, .77]	.533†
Repetition Ranges: 1=1-3 reps, 2=3-6 reps, 3=6-8 reps, 4=8-10 reps, 5=10-12 reps, 6=12-15 reps, 7=15+ reps.						
Load Range						
Upper Body Compounds	37	4	2	-1.99 [-2, -1.5]	-.89 [-.9, -.88]	<.001
Upper Body Isolation	28	4	2	-1.5 [-2, -1]	-.86 [-.91, -.78]	<.001
Lower Body Compounds	38	4	2	-1.99 [-2, -1.5]	-.88 [-.89, -.88]	<.001
Lower Body Isolation	29	4	2	-1.99 [-2, -1.49]	-.89 [-.91, -.88]	<.001
Trunk	16	4	2	-1.99 [-2.5, -1.49]	-.89 [-.92, -.89]	<.001†
Load Ranges (as % of estimated or actual 1RM): 1=<50%, 2=50-60%, 3=60-70%, 4=70-80%, 5=80-90%, 6=90-100%						
Proximity-to-failure						
Upper Body Compounds	36	9	7	-2 [-2.49, -1.75]	-.85 [-.88, -.78]	<.001
Upper Body Isolation	33	9	7	-1.75 [-2, -1.25]	-.82 [-.88, -.72]	<.001
Lower Body Compounds	39	8.5	7	-2 [-2.49, -1.75]	-.85 [-.88, -.8]	<.001
Lower Body Isolation	34	9	7	-2 [-2.49, -1.75]	-.86 [-.88, -.8]	<.001
Trunk	21	8	6	-1.75 [-2.25, -1.25]	-.76 [-.88, -.54]	<.001
RIR/Proximity to Failure Scale (5-10 scale with increments of 0.5): 5=5 repetitions from failure, 7=3 repetitions from failure, 8.5= Definitely could complete one more repetition, chance at two, 9.5=No more repetitions but could utilise a heavier load, 10= Failure.						

Note. WBPW = week before peak week, PW = peak week, CI = confidence interval, 1RM = one repetition max, RIR = repetitions in reserve. † Continuity correction applied. Effect size (r) values of <.3, .3-.5, and >.5 were considered small, medium, and large effects, respectively.

4.4 Discussion

The aims of this study were to investigate the RT variables manipulated by physique athletes during PW and to discern any associations between competitor characteristics and these variables. Further, the magnitude of change from WBPW to PW were assessed in those who manipulated these RT variables. To our knowledge, this was the first study examining the RT practices of physique athletes during PW by making comparisons to the WBPW. Our results indicate that physique competitors vary their RT practices between WBPW and PW; however, there was no association between these manipulations and competitor characteristics. Among competitors who manipulated these variables, training frequency, total set volume, and load ranges, and RIR decreased, while for repetition range, only UBC and LBC changed significantly. The training splits employed for WBPW and PW also differed.

The frequencies of each RT variable revealed that the RT variables included within this study are widely manipulated by competitors during PW; however, none of the competitor characteristics were predictive of the variables manipulated. Further, the significant predictors within these non-significant models had very little effect on their respective outcome, indicated by the CI of the odds ratios ranging from 1-1.22. Given the diversity of our sample compared to a previous survey exploring PW nutrition in natural British bodybuilders competing in a single federation [30], and several others examining the pre-competition training practices in male bodybuilders [21, 69, 150], these models likely require larger sample sizes to detect relationships between competitor characteristics and the RT variable of interest. We observed similar variability when modelling nutrition strategies during PW [168] and concluded low sample size and the potential for uncaptured variables as potential explanations. Indeed, factors more predictive of RT variable manipulation than captured here may exist, highlighting the need for further research in the area.

Among competitors who manipulated RT variables, training frequency, and total, UBC, UBI, LBC, and trunk set volume decreased from WBPW to PW. One of the primary goals of physique athletes is to maximise muscle mass. While greater hypertrophy is associated with set volume mediated by higher RT frequency [169, 170], both variables were significantly lower than WBPW which may indicate a deliberate de-load during PW. Interestingly, LBI set volume had the smallest ES and did not decrease significantly. This might be explained by athletes compensating for substantial reductions in LBC set volume, and ensuring the lower body musculature received some stimulus while dissipating fatigue in consideration of the psychological demands associated with large muscle groups and loads [171]. It is likely that these overall changes in set volume may have been facilitated by training split modifications, allowing for the reorganization of exercises within PW to reduce stress closer to competition.

The interrelated nature of repetitions, load, and RIR can be observed in our data. All load ranges decreased significantly from the WBPW medians of 70-80% of 1RM to the PW median of 50-60%. Additionally, the median repetition ranges for PW were 12-15 for all body part and exercise types, from which UBC and LBC increased significantly from their WBPW median range of 8-10 repetitions. With all repetition ranges shifting upward for PW, load was also decreased, seemingly to facilitate the increase in repetitions performed. Additionally, competitors trained further from failure. This is despite evidence that higher exercise intensity may promote greater hypertrophy [172], further indicating a homogenous strategy amongst physique athletes to taper and reduce training stress during PW.

It is conceivable that reductions in training stress may have been achieved with a decrease or maintenance of repetitions in combination with the manipulation of other RT variables; however, an increase in repetition ranges was observed. This is feasibly part of a widely practiced CHO loading strategy whereby CHO loading is preceded by a glycogen depletion phase [30, 149, 168] during which training tapers have been reported among male bodybuilders [24]. Based on evidence that glycogen storage is promoted by prior depletion and impaired by muscle damage [26–29], Escalante and colleagues [2] recommend performing high repetitions while minimising muscle damage to enhance glycogen supercompensation and thus, muscle size. As muscle damage is seemingly greater with higher loads, at least within the free weight squat exercise [173], and with moderate and high repetition sets depleting glycogen considerably [174–176], the use of low-load, high repetition sets that are further from failure may be justified. Additionally, exercise selection changes being implemented by 46% of respondents may indicate a shift to exercises that may be more suited to lower loads and higher repetition ranges. Exercise selection modifications could have also involved the removal of heavily loaded eccentric exercises and/or exercises that train muscles at long lengths as they incur greater muscle damage [177, 178].

Further, the visual perception of leanness may be enhanced by a reduction in muscle damage. While speculative, the extracellular swelling and intracellular oedema response to muscle damage [179–182] may obscure muscular definition and impair performance in divisions that require it. Additionally, the posing ability of the competitor may be affected by muscle soreness and the reduced neuromuscular performance associated with excessive muscle damage [179, 180, 183]. As posing requires isometric contractions to display muscularity and definition in certain divisions as well as coordination of movement to execute the relevant poses [184], reducing muscle damage during PW may enhance muscle definition and posing ability.

There may be instances, however, where muscle damage can be leveraged to enhance performance. As the response to muscle damage also manifests as increased muscle size [182, 185, 186], there may be application for divisions where extreme muscle definition is not desired, and the development of certain body segments is emphasised [161]. In practice, this could be performing sets to or very close to failure in the body segments of interest close to competition to transiently increase muscle size and obscure definition. While our results do not support the implementation of such practices in our sample, it is possible that it could be observed with a greater variety of divisions. Nonetheless, experimental research is required to evaluate the effects of this strategy before concrete recommendations can be made.

Similar to the nutrition section of our survey [168], certain limitations are present within this study. This survey was mainly distributed by social media exercise science communicators which may have restricted the reach of the survey, whereby only a certain segment of competitors may have responded. Additionally, the number of eligible competitors who were not reached or did not respond to the survey cannot be determined, constraining the generalisability of the results. Each response was screened for unambiguously false information; however, due to the nature of the online questionnaire, it is plausible that responses were affected by biased or incomplete recollections, or fabrication. Thus, fabricated responses which may appear legitimate may not have been detected in the screening process, which has implications for the validity of the data. To minimise such responses, participants were made aware that the survey was anonymous and that their information would be unidentifiable. Furthermore, the training section of the survey was designed to include as many checkboxes and drop-down options of discrete categories (i.e., training split types and load ranges) as possible, which may have reduced participant burden and recall bias of certain details.

As this was a very large survey, the RT variables of interest were selected based on what the research team believed to be most relevant for PW in relation to nutritional strategies (i.e., using high repetitions to deplete glycogen). Thus, certain RT variables such as intraset recovery time and advanced training techniques were not examined. There is also potential that certain RT variables which participants needed to estimate do not reflect their true values. Load range is an example of this as it is unlikely that all competitors trained using percentages of their true 1RM and would have estimated the reported values. Likewise, subjective estimations of RIR may lack accuracy, particularly with higher repetitions, further away from failure [187]. While training experience was not captured by the survey, it is not unreasonable to assume that competitive physique athletes are more experienced in accurately estimating such variables than other resistance trained populations [188]. Further, within-subject comparisons were made to compare the directionality and magnitude of these variables, whereby the estimations would likely be reliable across WBPW and PW. Therefore, it should be considered that these comparisons provide further insight on the intended strategies of the competitors rather than to obtain a true measurement for these variables.

Our findings suggest that physique athletes reduce training stress during PW. However, the only experimental trial relevant to peaking for physique sport implemented a RT protocol considerably higher in volume and intensity than the results from this survey [18]. Such disparity between research methodology and real-world practices limits the generalisability of results to competitors. Thus, highlighting the importance of empirical cross-sectional evidence to ensure the ecological validity of experimental designs. While existing research examines the pre-competition training practices of physique athletes, this is the first study to specifically examine PW RT practices by making comparisons to WBPW. A larger sample size would have resulted in more precise results and reduced type II error probability when assessing the relationship between competitor characteristics and RT variables manipulated. While these results highlight the varied RT practices during PW, those who manipulated RT variables broadly did so to reduce training stress. While further detail is required to determine the motivation behind these practices, it can be hypothesised that to improve performance, competitors (depending on the division of competition) aim to dissipate fatigue, reduce muscle swelling, and deplete glycogen while minimising muscle damage to promote glycogen storage. To further our understanding of these practices, more concentrated surveys pertaining to RT practices during PW which investigate the rationale behind these practices should be implemented. Specifically, such surveys could also examine the number of exercises per muscle groups, number of sets per exercise, recovery time between sets and exercises, and the use of "advanced training techniques" (e.g., rest pause and supersets). Additionally, such surveys should strive to capture larger samples to explore competitor variables that better predict PW RT manipulation. Finally, the findings of this research can be used to develop experimental designs which examine the peaking strategies implemented by competitors.

4.5 Practical Applications

Based on the findings of this research, we cannot recommend the implementation of any specific strategy based on characteristics such as drug-use status, sex, and division of competition of the competitor. However, physique sport coaches and competitors may consider the manipulation of RT variables during PW which could enhance on-stage presentation and performance. Accordingly, RT adjustments could be made to reduce training stress which may aid performance by dissipating fatigue and psychological stress, clearing oedema (which may enhance muscle definition), reducing delayed-onset muscle soreness, and thereby maximising the posing ability of the competitor. Such reductions in training stress may be achieved by modifying the RT variables of frequency, set volume, load, and proximity-to-failure. While no exact values for changes in these variables can be recommended, reductions relative to the preceding weeks of RT may be most practical. Additionally, the depletion of glycogen stores while minimising muscle damage to enhance CHO loading strategies may be achieved by performing higher repetition ranges (i.e., 12-15 repetitions) with lower loads (i.e., 50-60% of 1RM), further from failure. Muscle damage may also be reduced by removing heavily loaded eccentrics and exercises that place muscles at long lengths. This may include exercises such as Romanian deadlifts, seated hamstring curls, chin-ups, and overhead triceps extensions. Contrastingly, for divisions which do not require extremely low levels of adiposity and emphasise the development of certain muscle groups, inducing further muscle damage which acutely increase muscle size and circumferences may be beneficial. An example of this may be for bikini competitors to perform primarily hip extension exercises (i.e., hip thrusts and full-depth squats) at high volumes and/or intensity before competition to transiently increase hip musculature size. Changes in training splits may also be implemented to accommodate these manipulations and the requirements of the nutritional PW strategy (i.e., to maximise glycogen depletion). However, as results were obtained only from those who manipulated these variables and the efficacy of these strategies were not tested, these recommendations should be individualised, tested before competition, and implemented with caution.

Chapter 5: The Concurrent Validity of a Portable Ultrasound Probe for Muscle Thickness Measurements

Preface

Chapter 2 highlighted the small body of research relating to the peaking practices of physique competitors and the overall difficulty in recruiting participants for such studies. Reducing the difficulty of collecting data onsite and otherwise increasing distance data collection opportunities, will hopefully improve participant recruitment for such studies. Valid and reliable portable research instruments are required in such situations to measure relevant outcomes. For example, body composition measurements such as MT are consistently reported in the physique sport literature and are required to evaluate the efficacy of the strategies discussed in Chapters 3 and 4. Obtaining such measurements, however, require laboratory-grade ultrasound devices which can be expensive and are constrained by their transportability, thus, limiting its utility for research where flexibility in the location of data collection may be needed. Fortunately, portable ultrasound probes such as the Lumify, are a more cost-effective and transportable alternative to laboratory-grade conventional devices. However, before the Lumify can be properly utilised in research (and in practice), validation against a "gold-standard" criterion is required. Therefore, the following Chapter evaluated the concurrent validity of the Lumify portable ultrasound probe by determining its agreement with a gold-standard device (i.e., the Vivid S5) for MT measurements. In addition to satisfying thesis aim 3, such evidence is important for maximising participation in physique sport research and aiding practitioners in conducting valid field-based body composition assessments.

This Chapter is in preparation for submission to the *Journal of Strength and Conditioning Research.*

5.1 Introduction

Muscle size (and therefore mass) is crucial for physical function [189, 190], health [191], and competitive success in physique sports [1], as well as benefitting performance in traditional sports [192]. Change in skeletal muscle size is a critical outcome in assessing adaptation to RT which can be determined by a variety of methods, such as B-mode ultrasound imaging [193]. MT measurements [194, 195], as well as estimations of muscle volume [196, 197] and mass [198, 199] derived from measures of MT have been validated against MRI. While MRI is more sensitive than ultrasound in estimating changes in muscle size via MT measurements, strong correlations between ultrasound MT and MRI derived muscle CSA highlight the utility of ultrasound imaging in evaluating longitudinal muscle size changes [200]. Nonetheless, with the advent of broad variations in the technology, understanding the bounds of their utility for practice is important.

While ultrasound offers a time-effective, safe, and non-invasive measure of muscle architecture, high-end devices are expensive and generally constrained to a singular location due to their lack of transportability, limiting their application in the field [33]. In contrast, new portable hand-held devices such as the Lumify (Philips Healthcare, Amsterdam, Netherlands) offer a more cost-effective and viable alternative to stationary devices, thus enhancing the accessibility of field testing. Ultimately, these portable devices have the potential to enhance body composition assessments in the field as ultrasound MT measurements are more sensitive to changes in muscle size than commonly implemented surface anthropometry techniques [32].

The hand-held Lumify device has been examined within gynaecological imaging [201] and for optic nerve sheath diameter measurements [202] where the device was comparable to a diagnostic ultrasound unit and a laptop-associated portable unit, respectively. Further, this device has been used in plastic surgery [203] and in the education of medical students who were novice scanners [204]. Most recently, Ritsche and colleagues [33] conducted a comparative study between the handheld Lumify and a high-end laboratory ultrasound device. In that study, muscle architecture measurements between devices were comparable, with measures of MT having the highest agreement [33]. While this is an important first step in the validation of the Lumify device, assessment of other muscle groups, particularly of the upper body is required to comprehensively evaluate the validity of the device in measuring MT across different regions of the body.

To our knowledge, the validity of MT measurements using the Lumify device for both the upper and lower limb has not been investigated. Examination of the upper limb is important as the MT values are generally smaller than that of the lower limb [205], which may influence the agreement between devices. Furthermore, comparisons at a larger number of sites may minimise any potential biases unique to each measurement site. This is relevant for both researchers and practitioners as valid portable probes would allow simplified data collection procedures for evaluating cross-sectional information on MT and evaluating longitudinal changes in muscle size. Therefore, the aim of this investigation was to determine the concurrent validity of the portable Lumify probe and its agreement with the GE Vivid S5 (General Electric Company, Boston, USA) for MT measurements of both the upper and lower limbs within a resistance-trained population.

5.2 Methods

5.2.1 *Study Design*

A repeated-measures design was used to assess the concurrent validity of the Lumify device and evaluate its agreement with a stationary ultrasound device in measuring MT at five different muscle sites. Testing for each participant was completed in one visit to the laboratory, where anthropometrics was recorded followed by the marking of measurement sites. Subsequent ultrasound imaging of the five measurement sites using both devices, was conducted in the following order: anterior upper arm, anterior thigh, posterior arm, posterior thigh, and posterior lower leg. Three images were captured by each device at each site, from which the means were used to assess the agreement between devices.

5.2.2 *Participants*

Eighteen participants (Table 5-1 Participant demographics) completed this study following the provision of their written informed consent. To be eligible for inclusion, participants were required to be above the age of 18, currently engaging in regular RT, have no existing injury or physical disorder at the sites of measurement, and have refrained from vigorous physical activity in the previous 24 hours. Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC reference number: 20/282).

5.2.3 *Data Acquisition and Preparation*

Table 5-1 Participant demographics

Sex	*N*	*Age (years)*	*Height (cm)*	*Body Mass (kg)*
Male	9	26±5.85	180.22±6.01	87.84±9.95
Female	9	24.89±5.79	169.13±7.73	63.87±6.47
Total	18	25.44±5.68	174.67±8.81	75.86±14.59

Note. Age, height, and weight are presented as mean±*SD*.

To evaluate the concurrent validity of the Lumify probe, the stationary Vivid S5 was used as the comparative device as it has been employed to assess MT within recent research [206, 207]. Images on the Lumify were scanned using the L12-4, linear-array 37mm probe set on the Musculoskeletal application. A Samsung Galaxy Tablet S7 FE (Samsung, Seoul, South Korea) was used as the display for the Lumify probe via a wired USB-C connection through the Lumify application (version 4.04). For the Vivid S5 device, the 12L-RS, linear 48mm probe with frequency set to 10 MHz was used. Gain/depth at each site was not standardised between devices and adjusted by the operator as desired. However, these settings were kept consistent within each device for the three images captured at each site. Measures of MT were obtained in the transverse plane and were based on those assessed previously [199, 205, 208, 209], as described and displayed in Table 5-2 *Measurement sites and limb positioning for ultrasound muscle thickness measurements.* and Figure 5-1 *Limb positioning for each of the scanning sites.*, respectively.

Table 5-2 Measurement sites and limb positioning for ultrasound muscle thickness measurements.

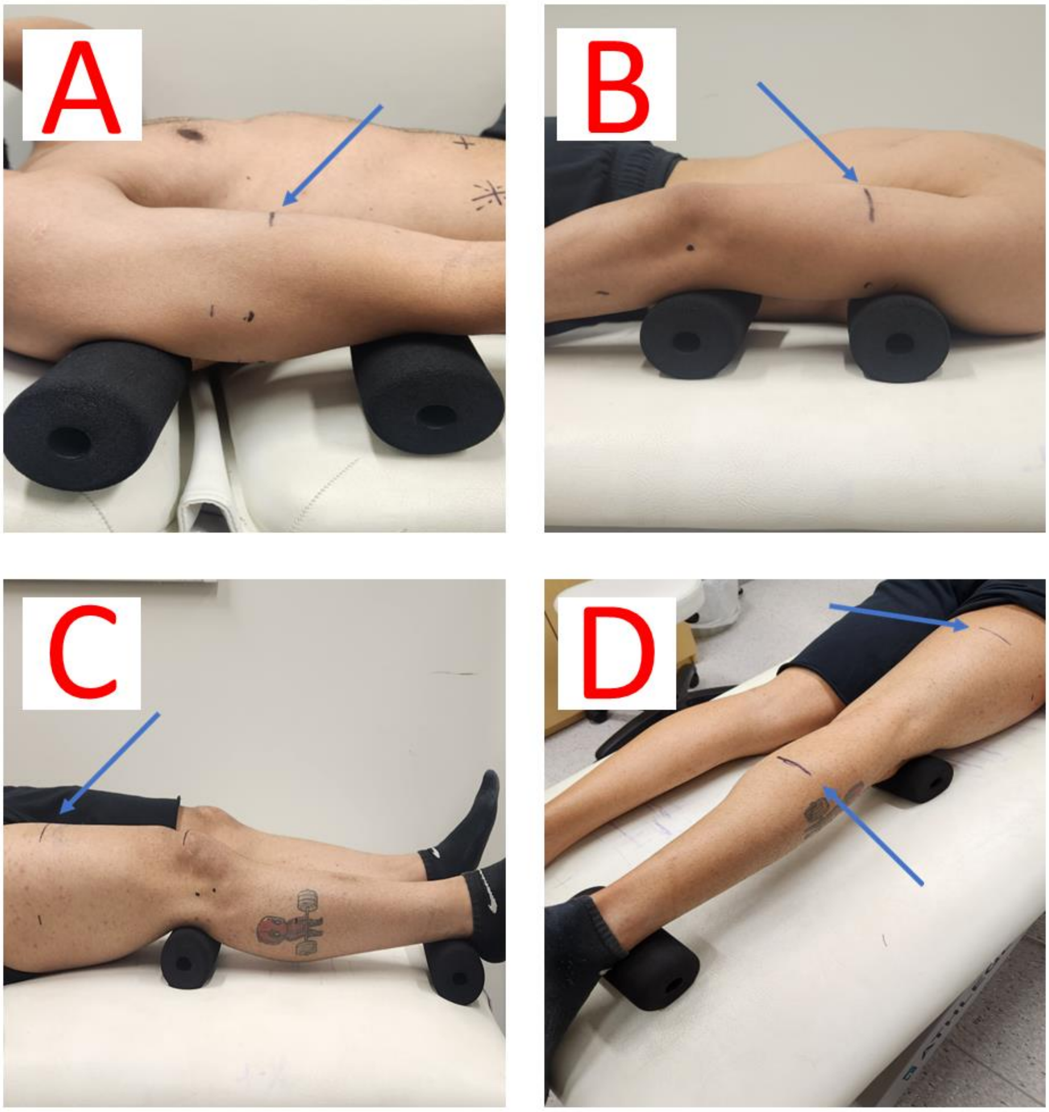
Measurement Site	*Image Plane*	*Location*	*Limb Positioning*
1 Anterior upper arm	Transverse plane over the anterior humeral shaft	Distal to the acromion process of the shoulder, 60% of the measured distance between the acromion process of the scapula and the lateral epicondyle of the humerus	In supine, elbow extended with foam rollers placed beneath the most proximal and distal parts of the humerus (within the arm pit and beneath the triceps brachii tendon, respectively)
2 Posterior upper arm	Transverse plane over the posterior humeral shaft		In prone, elbow extended with foam rollers placed below the most proximal part of the humerus (within the arm pit) and in the cubital fossa
3 Anterior thigh	Transverse plane over the anterior femoral shaft	Distal to the greater trochanter, 50% of the measured distance between the most superior edge of the greater trochanter and the most distal prominence of the lateral condyle of the femur	In supine, knee extended with foam rollers placed in the popliteal fossa and beneath the Achilles tendon
4 Posterior thigh	Transverse plane over the posterior femoral shaft		In prone, knee extended with foam rollers placed beneath the quadriceps tendon and the talocrural joint
5 Posterior lower leg	Transverse plane over the fibula shaft	Distal to the lateral condyle of the tibia, 30% of the measured distance between the most superior prominence of the lateral condyle of the tibia and the most inferior prominence of the lateral malleolus of the fibula	

Note. Measurement site image plane and location as described by Thoirs & English [205]. Measurements were collected in the following order: anterior upper arm, anterior thigh, posterior upper arm, posterior thigh, and posterior lower leg. These sites were chosen as they are commonly used to assess body composition changes in response to resistance training interventions.

Participants reported to laboratory, following >24 hours without vigorous physical activity which was verbally confirmed upon arrival. As data collection was completed within one session, hydration status and the use of supplements which may influence intramuscular body water content were not controlled. The height and BM of each participant were obtained upon presentation using a wall-mounted stadiometer (Harpenden Stadiometer; Holtain Limited, Crosswell, Wales) and a scale (HW-200KGL; A&D, Tokyo, Japan), respectively. Following this, the exact sites of measurements for each participant were determined by an International Society for the

Advancement of Kinanthropometry (ISAK) certified practitioner. The sites were marked using a permanent marker, where a horizontal line with a vertical check line was marked to guide the orientation and positioning of the probe along the line to maximise the accuracy of measurements between devices. Each limb was elevated with two foam rollers (diameter = 7cm) in accordance with the methodology described in Table 5-2 *Measurement sites and limb positioning for ultrasound muscle thickness measurements.* to ensure that the musculature of interest was relaxed during the measurements. All images for this study were obtained by the same operator. Intra-rater reliability of the operator for each site (ICC=.92-.99, CV=1.81-4.91%, SEM=0.07-0.28cm) was determined from measurements collected from three participants not involved in the study on three separate occasions within a two-hour period. All intra-operator reliability data is made available in the online supplementary material.

Figure 5-1 Limb positioning for each of the scanning sites.

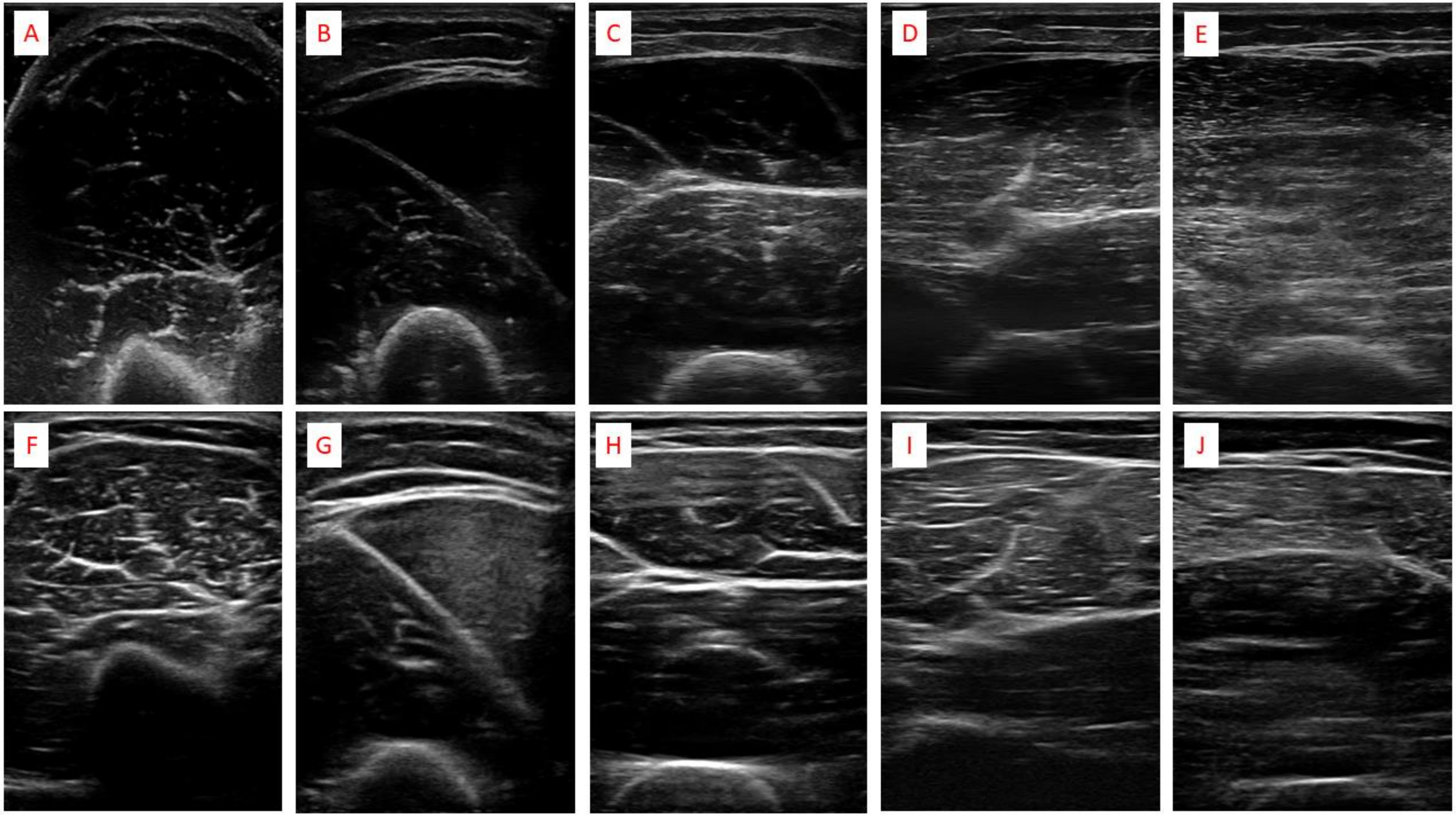


Note. The measurement sites are as follows: **A)** anterior upper arm, **B)** posterior upper arm, **C)** anterior thigh, and **D)** posterior thigh and posterior lower leg. Blue arrows indicate the site of measurement. Please refer to Table 5-2 *Measurement sites and limb positioning for ultrasound muscle thickness measurements.* for specific detail on limb positioning.

A water-soluble transmission gel was applied to the probe which was then placed on the check line marked on the skin. Images were taken in triplicate in the transverse plane with the transducer placed on the skin with the least amount of pressure required to obtain a clear image. Measurements at all five sites were taken with one device first in the same order for each participant, before repeating the measurements with the other device. To counterbalance and account for any order effects, the Lumify probe was used first for the first nine participants and second for the other nine. Anterior measurements were collected first in a supine position before the participant was positioned in a prone position for the posterior measurements.

Captured images saved on each device were exported for analysis in ImageJ (Java 1.8.0_172). Images were analysed in a randomised order, where a scale was manually set for each image by superimposing a line onto the scale prior to measurement. MT was determined as the linear vertical distance from the apex (the most superficial pixel) of the periosteum to the deep fascia (the deepest pixel) superficial to the muscle tissue of interest and deep to the subcutaneous layer. The mean of all three measurements for each site was calculated and used for subsequent analysis. The within-device reliability of the Vivid S5 and Lumify L12-4 across all three measurements per participant are made available in the supplementary material. Examples of the images acquired by both devices can be seen in Figure 5-2 Ultrasound images acquired by the Vivid S5 and Lumify..

Figure 5-2 Ultrasound images acquired by the Vivid S5 and Lumify.



Note. *The top row (A to E) are images acquired by the Vivid S5, and the bottom row (F to E) are images acquired by the Lumify. Sites of measurement from Left to Right for both rows: anterior upper arm, posterior upper arm, anterior thigh, posterior thigh, and posterior lower leg.*

5.2.4 *Statistical Analysis*

Data for MT are presented as means and *SD*. The normal distribution of the data was confirmed using the Shapiro-Wilk test (p>.05). Paired samples t-tests with Cohen's *d*, Bland-Altman plots (systematic bias, random error, and 95% limits of agreement [LoA]) and Pearson's product–moment correlation coefficient (r) were used to assess the concurrent validity of the Lumify device. A regression line of the differences was also fitted to each Bland-Altman plot to detect any proportional bias [210], which was determined as being present when $r^2 \geq .1$ [211]. Where any proportional bias was detected with this method, the data at that site was logarithmically transformed before calculating *r* [212]. The criterion to interpret *r* was trivial (<.1), small (.1-.3), moderate (.3-.5), high (.5-.7), very high (.7-.9) practically perfect (>.9) [211]. Interpretation of ES was defined as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2), and very large (>2) [213], while significance for the paired t-tests was determined as p<.05. For LoA, bias, *r,* and ES, 95% CI were calculated to aid interpretation. Statistical analyses were performed in R language and environment for statistical computing (version 4.2.2, The R foundation for Statistical Computing, Vienna, Austria) [151] and with a custom spreadsheet [214]. Bland-Altman and correlation plots were constructed using the *SimplyAgree* [215] and *ggplot2* [157] packages, respectively. The dataset and custom R scripts utilised for this study are available at the Open Science Framework repository (https://osf.io/uft87/).

5.3 Results

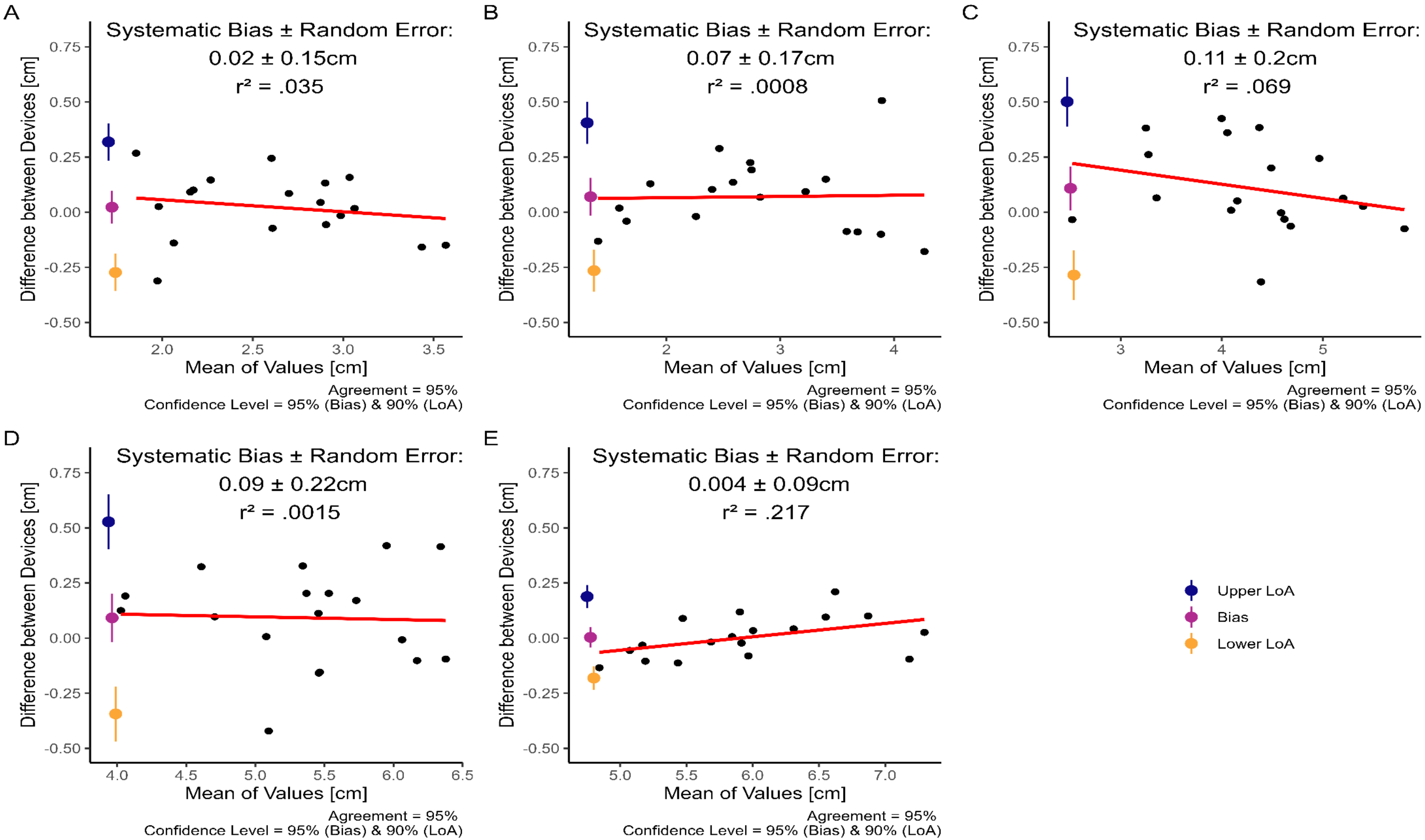
The mean and *SD* of MT measurements in addition to statistical parameters (bias, LoA, ES, and p-values) are presented in Table 5-3 Parameters estimated by Bland-Altman Analysis and statistical parameters to evaluate the agreement between muscle thickness measurements of the Vivid S5 and Lumify.. Bland-Altman plots displayed low systematic bias (≤0.11cm) and random errors (≤0.22cm) across all sites (Figure 5-3 Bland-Altman plots displaying the measurement of muscle thickness between the Vivid S5 and Lumify at each measurement site.). LoA were the widest for measurements collected at both the anterior and posterior thigh while the LoA were most narrow at the posterior lower leg where proportional bias was also detected ($r^2 = .217$). The correlations for MT between Lumify and Vivid S5 at all sites were practically perfect ($r \geq .95$) with only the lower CI bounds of the anterior arm and posterior thigh crossing the threshold for very high correlation (Figure 5-4 Correlation of muscle thickness measurements between the Vivid S5 and Lumify at each measurement site.). Paired t-tests revealed that MT between the devices differed only at the anterior thigh ($p<.05$), although the magnitude of difference across all sites was trivial ($ES \leq 0.13$).

Table 5-3 Parameters estimated by Bland-Altman Analysis and statistical parameters to evaluate the agreement between muscle thickness measurements of the Vivid S5 and Lumify.

Measurement Site	Vivid S5 Mean±*SD* (cm)	Lumify Mean±*SD* (cm)	Mean Bias (cm) [95% CI]	Lower LoA (cm) [95% CI]	Upper LoA (cm) [95% CI]	ES (*d*) [95% CI]	*p*
Anterior upper arm	2.63±0.51	2.61±0.54	0.02 [-0.05, 0.09]	-0.27 [-0.36, -0.19]	0.32 [0.23, 0.4]	0.04 [-0.09, -0.18]	.531
Posterior upper arm	2.84±0.87	2.77±0.87	0.07 [-0.02, 0.16]	-0.27 [-0.36, -0.17]	0.41 [0.31, 0.5]	0.08 [-0.01, 0.18]	.099
Anterior thigh	4.34±0.8	4.23±0.86	0.11 [0.01, 0.21]	-0.29 [-0.39, -0.17]	0.5 [0.39, 0.61]	0.13 [0.01, 0.24]	.035
Posterior thigh	5.43±0.7	5.33±0.71	0.09 [-0.02, 0.2]	-0.34 [-0.47, -0.22]	0.53 [0.4, 0.65]	0.13 [-0.02, 0.28]	.097
Posterior lower leg	5.97±0.75	5.96±0.7	0.004 [-0.04, 0.05]	-0.18 [-0.23, -0.13]	0.19 [0.14, 0.24]	0.005 [-0.05, 0.06]	.869

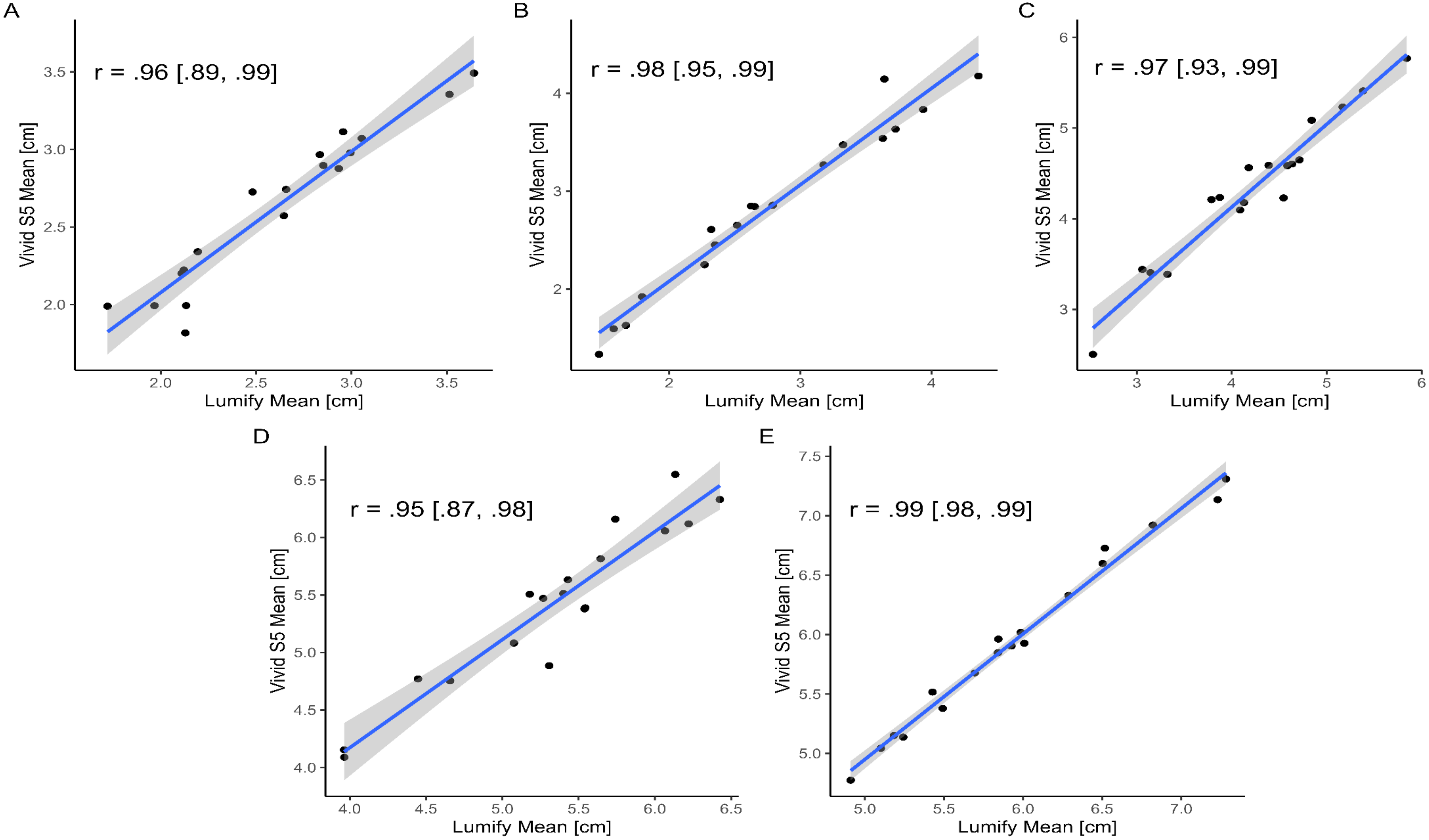
Note. *SD* = standard deviation, CI = confidence intervals, LoA = limits of agreement, ES = effect size, *p* was determined with a paired samples t-test.

Figure 5-3 Bland-Altman plots displaying the measurement of muscle thickness between the Vivid S5 and Lumify at each measurement site.



Note. Plots are of the measurement sites as follows: **A)** anterior arm, **B)** posterior arm, **C)** anterior thigh, **D)** posterior thigh, and **E)** posterior lower leg**.** Systematic bias, random error, 95% LoA with 95% CI, the regression line, and r^2 are presented within each plot.

Figure 5-4 Correlation of muscle thickness measurements between the Vivid S5 and Lumify at each measurement site.



Note. Plots are of the measurement sites as follows: **A)** anterior arm, **B)** posterior arm, **C)** anterior thigh, **D)** posterior thigh, and **E)** posterior lower leg**.** The linear regression line (blue) and Pearson's product-moment correlation coefficient (*r*) with 95% CI (grey shaded area) are displayed within each plot.

5.4 Discussion

This study assessed the concurrent validity of the Lumify L4-12 portable probe in measuring MT at five different sites. The agreement between Lumify and Vivid S5 devices were lowest at the anterior and posterior thigh (i.e., wider LoA, and significant differences between means for the anterior thigh) while being the highest at the posterior lower leg (i.e., narrowest LoA and highest *r* value). Proportional bias, which could signal concern, was detected at the posterior lower leg; however, as the LoA were narrow at this site (lower CI of the lower LoA=-0.23cm; upper CI of the upper LoA=0.24cm), and the absolute differences between devices trivial, this bias may be practically irrelevant. Practically perfect correlations between each device were observed at each site of measurement where the relationship was strongest at the posterior lower leg and weakest at the anterior arm and posterior thigh. Finally, the differences in MT between the devices were trivial at each muscle site. Therefore, the Lumify portable probe appears to be a valid device that is largely interchangeable with the stationary Vivid S5 in measuring MT.

Ultimately, we observed high levels of agreement between the Lumify and the Vivid S5 at all sites of measurements, in which agreement was the greatest at the posterior lower leg. This may have been a consequence of the site being the last site of measurement for both devices, which may have lessened the impact of intramuscular fluid shifts and increased accuracy. Interestingly, proportional bias was also detected at the posterior lower leg, which may be a result of the site having the highest MT values, leading to a greater potential for measurement error (i.e., manual scaling and measurement in ImageJ), especially for larger values of MT. However, the lowest r^2 value was found at the posterior thigh, which contained the second highest mean MT values, indicating that the proportional bias detected may be unique to the posterior lower leg. While proportional bias is of concern for practitioners, the low absolute differences between devices for all measurements at the posterior lower leg (ranging from -0.13-0.21cm) and trivial ES render this bias likely practically irrelevant. Further research is required to determine if proportional bias in the Lumify is present at other sites not examined in the current study.

To the best of our knowledge, this is the second study which has investigated the agreement between the Lumify and a stationary ultrasound device in measuring MT and the first to include the musculature of the upper body. Previously, Ritsche et al. [33]

evaluated the agreement between the Lumify and Acuson Juniper for muscle architecture measurements at three different lower limb sites. For measurements of MT, the bias reported by Ritsche et al. [33] at their measurement sites (ranging from -0.02 to 0.03cm) however, were lower than those found at ours (0.02 to 0.11cm), except for the posterior lower leg (0.004cm). While MT was assessed in both studies, distinct differences in methodology may have led to slightly different results. As Ritsche et al. [33] assessed muscle architecture (i.e., MT, fascicle length, and pennation angle), images were scanned longitudinally while our images were captured in the transverse plane. Ritsche et al. [33] also estimated MT using the semi-automated SMA tool which uses the mean distance between the two superficial aponeuroses of the entire image for measurements [216]. Thus, only the superficial muscles were evaluated, whereas we manually measured the linear distance from the bone to the aponeurosis, including both deep and superficial muscles. Finally, the comparison device employed by Ritsche et al. [33] was newer than ours which may have contributed to differences in findings. Notwithstanding these differences, 95% LoA was similar between studies except for the posterior lower leg in our study (difference between lower and upper LoA=0.36cm), which was again considerably lower than our other sites of measurement. The difference between lower and upper LoA for our other four sites ranged from 0.6-0.87cm, while those reported by Ritsche et al. [33] were between 0.49-0.79cm. Thus, indicating similar degrees of agreement between Lumify and the stationary device employed in each study for measuring MT [217].

While this research provides further evidence of the validity of the Lumify in measuring MT at different lower- and upper-body muscle sites, further research could strengthen the validity and reliability of the device. Namely, the determination and implementation of a practically meaningful threshold corresponding to the smallest detectable change in MT may allow for a more robust and relevant evaluation of the agreement in MT measurements between Lumify and valid stationary ultrasound devices. Further, as only young, healthy adults who engaged in regular RT were recruited for this study, the results may not be wholly generalisable to other populations, particularly those with more subcutaneous and/or less muscle tissue. Thus, comparisons between devices for the measurement of ST should also be considered for further research due to its importance as an exercise intervention outcome. Similarly, comparisons made for certain trunk muscles (i.e., abdomen and chest) may provide a comprehensive validation of the Lumify probe for MT measurements, thereby revealing any potential site-specific issues. Additionally, the test-retest reliability of either probe was not assessed across different days within the present study, meaning that the consistency of measurements of the Lumify could not be assessed or compared to Vivid S5 over multiple testing sessions. Finally, as the same operator may not always be available, the evaluation of interrater reliability would further the device's utility for practitioners.

5.5 Practical Applications

High levels of agreement between the Lumify and the Vivid S5 in the measurement of MT were found at five different muscle sites. Proportional bias was detected at the posterior lower leg; however, given the small absolute differences between devices and trivial ES, this bias may be practically irrelevant. Overall, it can be concluded that the Lumify probe is interchangeable with the Vivid S5 in making MT measurements at the five sites assessed when averaging across repeated measures. Thus, it appears to be an appropriate instrument for practitioners and researchers collecting MT measurements, providing a more cost-effective and transportable alternative to laboratory-based devices, and simplifying field-based data collection procedures.

Chapter 6: Discussion

6.1 General Summary

The overall purpose of this thesis was to examine the literature relating to peaking for physique sport and determine the current practices of competitors. Additionally, research from this thesis evaluated the validity of a portable ultrasound device in MT, an outcome measure relevant to physique sport research. Further to addressing some gaps identified in the literature and providing direction for future research, the findings from this thesis were intended to inform application for both coaches and competitors who already are or plan to implement peaking strategies for physique sport. To achieve the aims of the thesis (listed below for ease of comprehension), three primary research projects were conducted.

The specific aims of this were to:

1. Critically examine and appraise the existing literature relating to CHO manipulation during PW.
2. Investigate the nutritional and RT strategies implemented by competitors and whether the implementation of such strategies is influenced by competitor characteristics.
3. Validate a portable ultrasound device (Lumify) in the collection of MT measurements for use in future research within this area.

Before addressing the aims of this thesis, a brief background on the peaking practices of physique competitors was performed and is presented in Chapter 1. Following this, the literature relating to peaking for physique sport was synthesised and critically examined in Chapter Two to broadly address thesis aims 1 and 2. Specifically, a review of the literature pertaining to CHO manipulation practices during PW, the macronutrient around which peaking strategies are most often centred, was conducted. Current research limitations were highlighted with future directions, while broad practical applications are provided based on the findings. The limited research in this area forms the basis for Chapters 3 and 4 with the aim of generating a greater understanding of the PW practices of competitors. In Chapter 3, current PW nutrition strategies and how they relate to competitor characteristics was evaluated using a survey, in service of thesis aim 2. Notably, CHO backloading was the most implemented CHO-based strategy; however, no competitor characteristics predicted CHO-based strategies. For non-CHO strategies, water restriction was implemented more frequently by enhanced competitors than natural, while sodium loading was more likely to be practiced by males and professionals in comparison to females and amateur competitors, respectively. Most respondents commenced their peaking strategy five-to-eight days before competition, but peaking strategy length was not predicted by any of the variables. Finally, males were more likely to have a greater disparity between the lowest and highest daily CHO intake during PW than females, which may indicate a more extreme peaking protocol. These results highlight the most prevalent peaking strategies and their length, while also discerning their relationship (or lack thereof) with competitor characteristics.

Analogous to Chapter 3, the relationship between competitor characteristics and their RT variables were explored in Chapter 4 using the same survey. Differences in RT variable manipulation between WBPW and PW was explored among those who manipulated RT during PW. No competitor characteristics predicted RT manipulation during PW. In those who manipulated RT, frequency, set volume, load, and proximity-to-failure were reduced in PW, while repetition ranges for compound exercises increased, which may indicate a deliberate decrease in training stress. Practical applications for the manipulation of these RT variables during PW were provided based on the findings, including the likely individualised nature of strategies employed. Overall, this chapter contributed to addressing thesis aim 2.

As discussed within Chapter 2, participant recruitment for physique sport research is difficult. Accordingly, travel may be required for data collection to maximise participant recruitment. As such, portable tools that are valid and reliable are a necessary step to addressing important questions in the field. Thus, the agreement between a recently developed portable ultrasound probe (i.e., the Lumify) and a stationary criterion measure (i.e., Vivid S5) in measuring MT was evaluated in Chapter 5 to realise thesis aim 3. Systematic bias and random error of the Lumify device was low while the correlation between devices were practically perfect and the differences trivial. Proportional bias was detected at the posterior lower leg; however, the LoA were narrow at all measurement sites, indicating that the Lumify device is interchangeable with the Vivid S5 for measuring MT. These results indicate the future is promising for more flexible, field-based assessment of important metrics for this cohort.

The methodological limitations in the small, but growing body of peaking research were highlighted within this thesis. Additionally, the current PW nutrition and RT practices across a broad population of competitors were explored through a survey. Given the logistical recruitment challenges in physique sport research, the concurrent validity of the Lumify portable ultrasound device was evaluated and confirmed for MT measurements. In summary, the findings from this thesis highlight the limitations and gaps in the literature and furthers the understanding of the current peaking practices of competitors, providing direction for future research and practical applications for both coaches and competitors.

6.2 Practical Applications

This thesis was intended to inform the coaching and athlete PW practices. To this end, several practical applications were identified.

1. When implementing a CHO load within a peaking strategy, loading with sufficient CHO (i.e., 3-12g/kg BM) is likely required to increase muscle glycogen content. The relevant division-specific criteria or individual requirements should be considered when selecting the amount of CHO to load with. Loading with high GI and low fibre CHO would likely enhance the rate of glycogenesis while reducing the potential for gastrointestinal symptoms and abdominal bloating.
2. An individual response pattern should be established to optimise the amount of CHO loaded to enhance performance. This can be done before competition by practicing and trialling peaking strategies in similar physiological conditions to PW, and by using information from previous competitions. The amount and source of CHO should be recorded, as well as the visual physique changes and their time course. Additionally, increased RT performance and psychological benefits related to CHO loading may occur and should be noted. Such practice runs may also allow competitors to acclimate to high CHO intakes, possibly reducing gastrointestinal stress before competition.
3. The menstrual cycle, which may influence glycogenesis, can be affected during contest preparation. Thus, it may be important for females to trial various strategies during different phases of the menstrual cycle before competition.
4. As stress may plausibly negatively impact appearance, establishing an individual response pattern and avoiding extreme manipulation of variables during PW would reduce unpredictability and stress. Additionally, competitors could reduce training stress through a de-load and practice mindfulness techniques during PW to reduce psychological stress.

5. The efficacy of practices such as dehydration and sodium restriction with potassium loading to reduce ECW is unclear but may negatively affect performance. Dehydration can reduce muscle water and low ECW could impair the efficacy of the "pump-up routine". Similarly, fat loading has been proposed as a strategy to increase muscle size but relies on arguably unsubstantiated theoretical grounds and needs to be tested empirically before recommendations can be made.
6. Implementing a depletion phase with extremely low CHO may not be necessary to maximise glycogenesis (and may occur already through dieting). However, reducing CHO and employing a large energy deficit during depletion may allow competitors to reduce additional body fat if required.
7. If possible, achieving required leanness three to four weeks before competition and slowly increasing CHO intake may be a viable alternative to a strategy involving drastic variable manipulation. This approach may improve RT performance while also allowing CHO intakes to be adjusted based on physique changes well in advance of competition.
8. As muscle damage can impair glycogenesis and possibly obscure muscle definition through swelling or produce soreness which impedes posing ability, reducing PW training stress may be beneficial. Further, depleting glycogen through RT may enhance the efficacy of CHO loading. These combined goals could be achieved by modifying training frequency, set volume, load, proximity-to-failure, and exercise selection during PW, using WBPW as a reference. Specifically, performing high repetitions with lower loads further from failure versus higher loads may deplete glycogen while minimising muscle damage and fatigue. Exercises involving heavily loaded eccentrics and that place muscles at long lengths could also be removed to reduce muscle damage.
9. There are divisions which do not require extreme levels of leanness and emphasise development of specific muscle groups (i.e., upper body for physique and lower body for bikini competitors). Within these divisions, the intramuscular swelling response to muscle damage may be leveraged to reduce muscle definition and transiently increase size of the target muscle groups immediately before competition.
10. Peaking strategies should be tailored to the individual and division-specific judging criteria. While competitors likely implement different strategies based on their characteristics (i.e., sex, division, and drug-use status), it is difficult to

confirm the efficacy of these strategies as they need to be evaluated empirically (alike other recommendations provided). If such strategies are to be implemented, trialling them before competition seems prudent.

6.3 Directions for Future Research

This thesis highlighted many limitations in the physique sport peaking literature, with specific limitations of each experimental chapter (Chapters 3 to 5) outlined in their respective discussion sections. How these limitations might be addressed in future research, with respect to the results and learnings from this work, are summarised below.

1. Ecologically valid research is required to evaluate the efficacy of various peaking strategies for physique sport. Recruiting participants in similar physiological conditions (i.e., in a period of extended dieting and with comparable body fat levels) to competitors during PW is essential. Previous findings can be used to guide the inclusion criteria for participant body fat level. If thresholds cannot be derived from the literature for the division of interest, cross-sectional data should be obtained from competitors in the final week before competition to establish values for future studies.
2. The only experimental trial which sought to test a CHO loading protocol employed by bodybuilders did not replicate the exact practices of competitors. For results of a trial to hold greater ecologically validity and generalisability to competitors, strategies which reflect the current peaking practices of competitors is required. The findings from Chapters 2 to 4 provide insight into the current nutrition and training practices that can be implemented within future research.
3. Peaking strategies vary amongst competitors with those displaying certain characteristics more likely to adopt certain behaviours, perhaps due to differing divisional requirements. Testing these different protocols with relevant participants would have application for a broader segment of physique athletes. Additionally, testing sex differences in the response to CHO loading strategies as well as comparing the response during different phases of the menstrual cycle (or in its absence) would help inform the practices of female competitors.
4. To gain a greater understanding of how competitor characteristics (i.e., sex, division, drug-use status) relate to PW strategies, a simpler, concentrated survey might allow for a larger, but more specific sample to be captured and potentially

reduce statistical errors. Such surveys centred around specific divisions could guide future research designs for testing division-specific strategies.

5. Body composition outcomes are typically used as surrogate measures for physique sport performance. However, as competitive success is determined visually, subjective physique evaluations are more ecologically valid. Specifically, photographs of participants performing a selection of division-specific poses could be taken under controlled lighting during different phases of the protocol. These photographs could be sent to and scored to the divisional criteria by several certified judges blinded to the condition/phase of the protocol.
6. Changes in physique as quantified by subjective judging could be used to determine the relevance of body composition measures (i.e., surface anthropometry, ultrasound imaging, and body water distribution) for evaluating peaking protocols. Subjective judging could also be used to evaluate the proposed relationships between appearance and certain outcome variables (i.e., body water distribution and psychological distress).
7. Physique athlete recruitment is difficult; thus, future research could consider quasi-experimental designs. Despite the difficulty in establishing causality, higher participant recruitment would provide further insight on the efficacy of peaking practices. Additionally, crossover designs could be employed to increase statistical power; however, participant burden should be considered.
8. Researchers may need to travel to competitions and locations with large populations of physique athletes to maximise recruitment. In such situations, valid and reliable portable research instruments are required. While there is promising evidence for their utility, more research is required to comprehensively evaluate the validity and reliability of portable ultrasound probes in measuring MT across different populations (including physique sport competitors) for both research and practice.

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Appendices

Appendix A *Ethics approval for Chapters 3 and 4*

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

18 August 2022

Eric Helms
Faculty of Health and Environmental Sciences

Dear Eric

Re Ethics Application: **22/208 The Effect of Carbohydrate Loading on Bodybuilding Performance, Muscle Size and Mood States.**

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

Your ethics application for the anonymous survey has been approved for three years until 17 August 2025.

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 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.
8. 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.

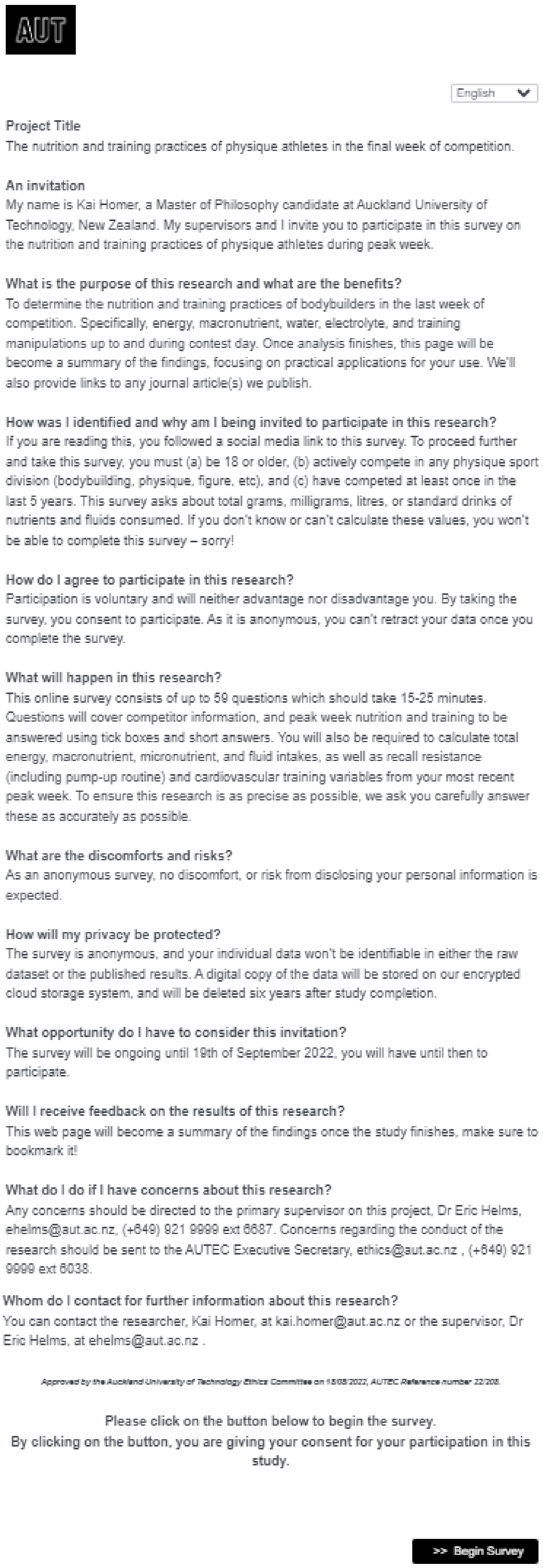
For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

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

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: kai.homer@aut.ac.nz; matthew.cross@aut.ac.nz

Appendix B *Consent form for Chapters 3 and 4*



Project Title
The nutrition and training practices of physique athletes in the final week of competition.

An invitation
My name is Kai Homer, a Master of Philosophy candidate at Auckland University of Technology, New Zealand. My supervisors and I invite you to participate in this survey on the nutrition and training practices of physique athletes during peak week.

What is the purpose of this research and what are the benefits?
To determine the nutrition and training practices of bodybuilders in the last week of competition. Specifically, energy, macronutrient, water, electrolyte, and training manipulations up to and during contest day. Once analysis finishes, this page will be become a summary of the findings, focusing on practical applications for your use. We'll also provide links to any journal article(s) we publish.

How was I identified and why am I being invited to participate in this research?
If you are reading this, you followed a social media link to this survey. To proceed further and take this survey, you must (a) be 18 or older, (b) actively compete in any physique sport division (bodybuilding, physique, figure, etc), and (c) have competed at least once in the last 5 years. This survey asks about total grams, milligrams, litres, or standard drinks of nutrients and fluids consumed. If you don't know or can't calculate these values, you won't be able to complete this survey – sorry!

How do I agree to participate in this research?
Participation is voluntary and will neither advantage nor disadvantage you. By taking the survey, you consent to participate. As it is anonymous, you can't retract your data once you complete the survey.

What will happen in this research?
This online survey consists of up to 59 questions which should take 15-25 minutes. Questions will cover competitor information, and peak week nutrition and training to be answered using tick boxes and short answers. You will also be required to calculate total energy, macronutrient, micronutrient, and fluid intakes, as well as recall resistance (including pump-up routine) and cardiovascular training variables from your most recent peak week. To ensure this research is as precise as possible, we ask you carefully answer these as accurately as possible.

What are the discomforts and risks?
As an anonymous survey, no discomfort, or risk from disclosing your personal information is expected.

How will my privacy be protected?
The survey is anonymous, and your individual data won't be identifiable in either the raw dataset or the published results. A digital copy of the data will be stored on our encrypted cloud storage system, and will be deleted six years after study completion.

What opportunity do I have to consider this invitation?
The survey will be ongoing until 19th of September 2022, you will have until then to participate.

Will I receive feedback on the results of this research?
This web page will become a summary of the findings once the study finishes, make sure to bookmark it!

What do I do if I have concerns about this research?
Any concerns should be directed to the primary supervisor on this project, Dr Eric Helms, ehelms@aut.ac.nz, (+649) 921 9999 ext 6687. Concerns regarding the conduct of the research should be sent to the AUTEC Executive Secretary, ethics@aut.ac.nz , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?
You can contact the researcher, Kai Homer, at kai.homer@aut.ac.nz or the supervisor, Dr Eric Helms, at ehelms@aut.ac.nz .

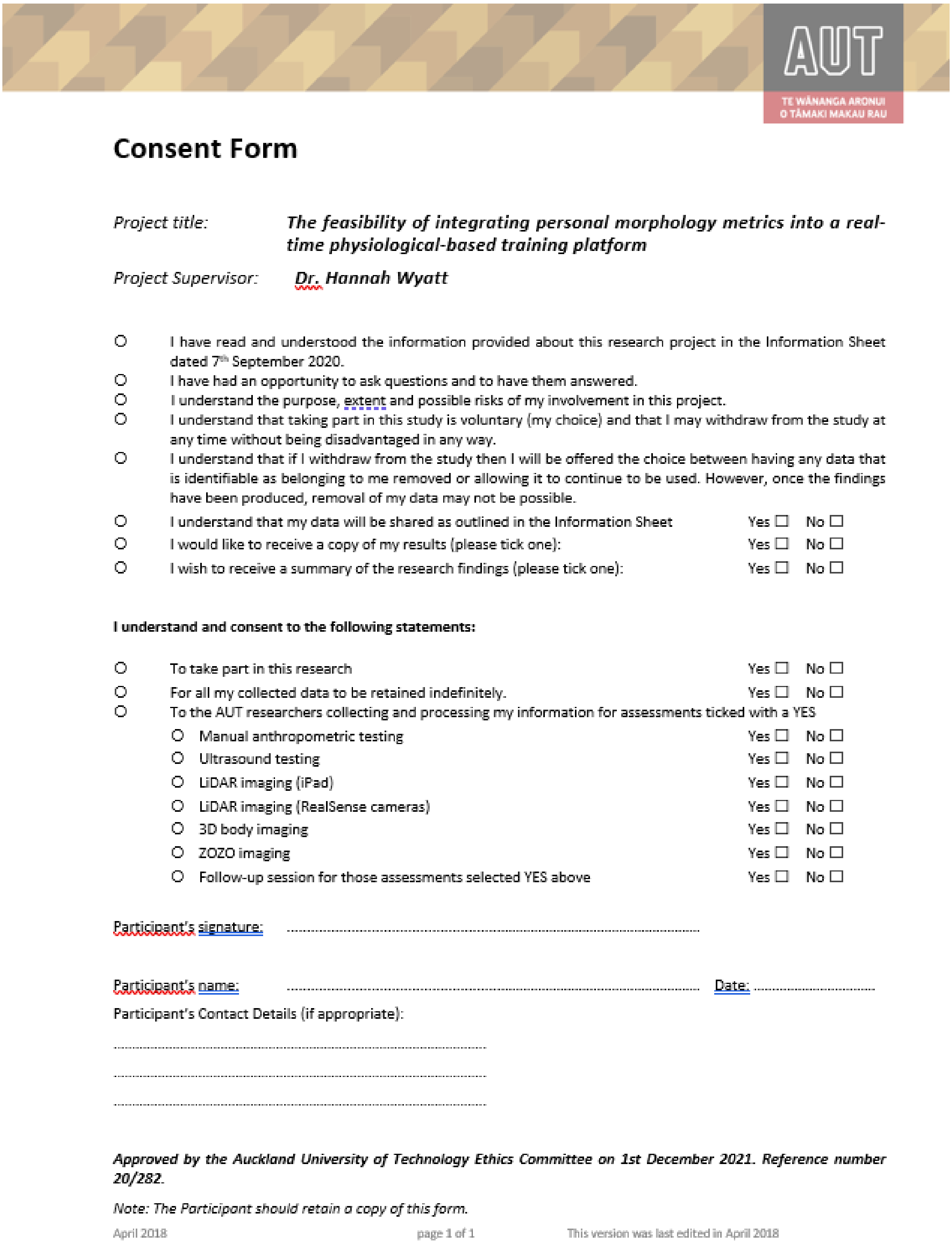
Approved by the Auckland University of Technology Ethics Committee on 15/08/2022, AUTEC Reference number 22/208.

Please click on the button below to begin the survey.
By clicking on the button, you are giving your consent for your participation in this study.

Appendix C *Questionnaire for Chapters 3 and 4*

The full questionnaire used to gather the data for Chapters 3 and 4 in this thesis can be found on the Open Science Framework using the following link: https://osf.io/a5czq.

Appendix D *Consent form for Chapter 5*



TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent Form

Project title: ***The feasibility of integrating personal morphology metrics into a real-time physiological-based training platform***

Project Supervisor: ***Dr. Hannah Wyatt***

○ I have read and understood the information provided about this research project in the Information Sheet dated 7th September 2020.
○ I have had an opportunity to ask questions and to have them answered.
○ I understand the purpose, extent and possible risks of my involvement in this project.
○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
○ I understand that my data will be shared as outlined in the Information Sheet Yes ☐ No ☐
○ I would like to receive a copy of my results (please tick one): Yes ☐ No ☐
○ I wish to receive a summary of the research findings (please tick one): Yes ☐ No ☐

I understand and consent to the following statements:

○ To take part in this research Yes ☐ No ☐
○ For all my collected data to be retained indefinitely. Yes ☐ No ☐
○ To the AUT researchers collecting and processing my information for assessments ticked with a YES
    ○ Manual anthropometric testing Yes ☐ No ☐
    ○ Ultrasound testing Yes ☐ No ☐
    ○ LiDAR imaging (iPad) Yes ☐ No ☐
    ○ LiDAR imaging (RealSense cameras) Yes ☐ No ☐
    ○ 3D body imaging Yes ☐ No ☐
    ○ ZOZO imaging Yes ☐ No ☐
    ○ Follow-up session for those assessments selected YES above Yes ☐ No ☐

Participant's signature: ....

Participant's name: .... Date: ....

Participant's Contact Details (if appropriate):

....

....

....

Approved by the Auckland University of Technology Ethics Committee on 1st December 2021. Reference number 20/282.

Note: The Participant should retain a copy of this form.

April 2018 page 1 of 1 This version was last edited in April 2018

Appendix E *Supplementary files for Chapters 3 to 5*

Supplementary Files for Chapters 3 to 5 in this thesis can be found on the Open Science Framework using the following link: https://osf.io/5vjfk/.