

# **Tapering Strategies to Enhance Maximal Strength**

**Hayden Joel Pritchard**

A thesis submitted to Auckland University of Technology in  
fulfilment of the requirements for the degree of  
Doctor of Philosophy (PhD)

2017

Primary Supervisor: Professor Michael McGuigan

Secondary Supervisor: Associate Professor Justin Keogh

Additional Supervisor: Dr Matthew Barnes

Sports Performance Research Institute New Zealand

Auckland University of Technology, Auckland, New Zealand

## ABSTRACT

Maximal strength is a physical quality imperative to success in strength sports and can also play a role in enhancing performance within many other sports. Tapering is a reduction in training load frequently undertaken prior to competitions in order to minimise training related fatigue and thus improve athletic performance. There is currently limited research for athletes and coaches to utilise when planning tapering to maximise strength at key events. This thesis investigated how strength-trained men can best structure the taper period to improve strength performance and attempted to identify the mechanisms underlying any performance improvements.

Two literature reviews (Chapters Two and Three) were performed to provide background information regarding training for maximal strength and summarise current knowledge on tapering for maximal strength. The literature revealed that maximal strength training should involve high intensity training (>80% one repetition maximum (1RM)), for multiple sets, with at least two sessions per week for each major muscle group. The current literature indicated that reductions in training volume (by 30-70%) with maintained, or slight increases, in intensity were most effective for improving maximal strength. However, optimal magnitudes of change during the taper were unclear. Short periods of training cessation (less than a week) were also found to be effective at enhancing, or maintaining, maximal strength.

The first study (Chapter Four) used a qualitative approach to determine strategies currently utilised by 11 elite New Zealand powerlifters (age =  $28.4 \pm 7.0$  years, best Wilks score =  $431.9 \pm 43.9$  points). Athletes reduced training volume by  $58.9 \pm 8.4\%$ , while maintaining (or slightly reducing) training intensity. The taper lasted  $2.4 \pm 0.9$  weeks, with the final resistance training session  $3.7 \pm 1.6$  days out from competition. Tapering was performed to achieve maximal recovery, and practices were largely informed through trial and error, with changes based upon 'feel'. Athletes usually removed accessory exercises and focused primarily upon the competition lifts during the taper.

The first training study (Chapter Five) involved a cross-over design to determine the effects of two durations, 3.5 or 5.5 days, of training cessation on performance following four-weeks of training. Eight resistance trained males (age =  $23.8 \pm 5.4$  years, bodyweight (BW) =  $79.6 \pm 10.2$  kg, relative deadlift 1RM =  $1.90 \pm 0.30$  times BW) completed the study. Combined data showed significant performance improvements, compared to pre-training, for both countermovement jump (CMJ) height ( $P = 0.022$ ) and isometric bench press (IBP) relative peak force ( $P = 0.011$ ) following short term training cessation (both small effect size (ES) = 0.30). This significant improvement was not present on the final training day, showing that training cessation was an effective means of enhancing strength and power. No significant differences were observed between 3.5 and 5.5 days of training cessation for any measure. These results suggest that a short period of strength training cessation can have positive effects on maximal strength expression, perhaps due to decreased neuromuscular fatigue.

The second training study (Chapter Six) also had a cross-over design to determine the effects of two variations in intensity (+5% or -10%) during a one week strength taper with volume reductions (-70%), following four-weeks of training. Eleven strength-trained males (age =  $21.3 \pm 3.3$  years, BW =  $92.3 \pm 17.6$  kg, relative 1RM deadlift =  $1.90 \pm 0.20$  times BW) completed the study. Combined data for both groups showed significant improvements in CMJ height over time ( $P < 0.001$ ), with significant improvements across all time points (pre- to post-training  $P = 0.010$ , ES = 0.23; pre-training to post-taper  $P = 0.001$ , ES = 0.37; and, post-training to post-taper  $P = 0.002$ , ES = 0.14). Combined data for CMJ flight time: contraction time also showed significant improvements over time ( $P = 0.004$ ), with significant improvements from pre- to post-training ( $P = 0.012$ , ES = 0.27). Combined data for isometric mid-thigh pull (MTP) relative peak force showed significant improvements over time ( $P = 0.033$ ), with significant increases found from pre- to post-training ( $P = 0.013$ , ES = 0.25). The higher intensity taper produced small ES improvements following the taper for CMJ height (ES = 0.43), CMJ flight time: contraction time (ES = 0.42) and MTP relative peak force (ES = 0.37). In contrast, the lower intensity taper only produced a small ES improvement for CMJ height (ES = 0.30). However, differences between groups were not significant. These results indicate that a strength taper with volume reductions can have positive

effects on maximal strength and power performance, with a tendency for higher intensity tapering to be more effective.

This thesis has documented current tapering practices of strength athletes and demonstrated both short term training cessation and volume reduced strength tapers as effective methods of improving maximal strength following training. When tapering, athletes should make substantial training volume reductions with little changes to training intensity. During a taper, training should focus on competition specific strength exercises, and strength training should cease a few days prior to important events.

## TABLE OF CONTENTS

ABSTRACT.....	II
ATTESTATION OF AUTHORSHIP .....	VII
ACKNOWLEDGEMENTS.....	VIII
CO-AUTHORED PUBLICATIONS .....	IX
LIST OF FIGURES.....	X
LIST OF TABLES.....	XI
LIST OF ABBREVIATIONS .....	XII
CHAPTER ONE .....	1
INTRODUCTION.....	1
1.1 Rationale.....	1
1.2 Purpose of Research .....	2
1.3 Significance of the Thesis.....	2
1.4 Structure of the Thesis.....	3
CHAPTER TWO .....	6
LITERATURE REVIEW ONE: RESISTANCE TRAINING FOR MAXIMAL STRENGTH: EFFECTIVE TRAINING METHODS AND ADAPTATIONS .....	6
Preface .....	6
Introduction .....	6
2.1 Intensity of Training .....	7
2.2 Training Volume .....	16
2.3 Training Frequency .....	22
2.4 Periodisation .....	30
2.5 Other Training Considerations.....	38
2.6 Application to the Thesis.....	43
CHAPTER THREE .....	44
LITERATURE REVIEW TWO: EFFECTS AND MECHANISMS OF TAPERING IN MAXIMIZING MUSCULAR STRENGTH.....	44
Preface .....	44
3.1 Introduction .....	44
3.2 Tapering .....	45
3.3 Training Cessation.....	54
3.4 Conclusions .....	60
3.5 Practical Applications.....	61
CHAPTER FOUR .....	62
TAPERING PRACTICES OF NEW ZEALAND'S ELITE RAW POWERLIFTERS .....	62
Preface .....	62

4.1 Introduction .....	62
4.2 Methods.....	64
4.3 Results.....	69
4.4 Discussion.....	76
4.5 Practical Applications.....	79
CHAPTER FIVE .....	81
SHORT TERM TRAINING CESSATION AS A METHOD OF TAPERING TO IMPROVE MAXIMAL STRENGTH .....	81
Preface .....	81
5.1 Introduction .....	81
5.2 Methods.....	84
5.3 Results.....	91
5.4 Discussion.....	94
5.5 Practical Applications.....	96
CHAPTER SIX.....	98
EFFECTS OF VARYING INTENSITY DURING TAPERING ON MAXIMAL STRENGTH .....	98
Preface .....	98
6.1 Introduction .....	98
6.2 Methods.....	101
6.3 Results.....	108
6.4 Discussion.....	110
6.5 Conclusions .....	113
CHAPTER SEVEN .....	115
GENERAL DISCUSSION AND PRACTICAL APPLICATIONS .....	115
7.1 Summary .....	115
7.2 Practical Applications.....	117
7.3 Limitations.....	119
7.4 Future Research Directions.....	120
REFERENCES.....	123
APPENDICES .....	135
Appendix A: Abstracts of Thesis Chapters .....	135
Appendix B: Abstracts of Poster Presentations .....	139
Appendix C: Isometric Bench Press Reliability Technical Note .....	143
Appendix D: Powerlifting Competition Reliability Technical Note .....	144
Appendix E: Additional Research Outputs since Beginning the Doctor of Philosophy.....	146
Appendix F: Ethical Approval .....	148

## 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.*

*Chapters Three, Four and Five, and Appendices A and B, have been published (or are currently in press) in peer-reviewed publications. The contributions to these papers from myself and by co-authors is outlined in the Co-authored Publications section, where each author has also approved the inclusion of the publication within this thesis and their respective contribution percentages.*



---

Hayden Joel Pritchard

## ACKNOWLEDGEMENTS

Firstly, to my supervisory team, Professor Mike McGuigan, Associate Professor Justin Keogh and Dr Matthew Barnes, your advice and support throughout the course of the thesis has been invaluable. Mike, you have consistently provided me with swift feedback and valued guidance on every aspect of the thesis. Your thoroughness and subject expertise has ensured the quality of my work and helped to shape me as a researcher. Justin, even from abroad you have managed to provide consistent support throughout my studies. From your input into the initial study design, through to critiques on every chapter, and encouragement throughout, thank you. Matt, I really appreciate the numerous times throughout this journey that I have been able to sit in your office to discuss ideas, interpret data and just talk shop. I am truly thankful to have had a supervisory team of such quality!

To UCOL, thank you for your support throughout my studies. To my managers backing my conference attendances and various consumable purchases, to all my colleagues who have put up with consistent PhD talk. Dr Bob, thanks for your assistance in data collection, your expertise with ELISA's and the consistent deliveries of ice. Shaun Hofenk, your help in the gym throughout each training study was of huge assistance.

Dr David Tod, thank you for your guidance in Chapter Four. Initially I knew very little about qualitative research and your expertise in this area has taught me skills I know I will utilise again. To all the powerlifters who discussed their tapering practices with me, I appreciate you being willing to share your experiences. To the numerous individuals who gave up their own training for many months to volunteer for the training studies, this research could not happen without you, thank you.

To my family and friends. Some of you may have seen a little less of me than you may have liked at times over the last three and a half years, but thank you for your support and encouragement throughout. Mum and Dad, I hope I have made you proud.

Lastly, and most importantly, Sash. Thank you for putting up with me when I have been stressed, frustrated and tired. You always support me. I love you.

## CO-AUTHORED PUBLICATIONS

**Table I.1:** Thesis publications

Chapter	Publication Reference	Contribution
Three	Pritchard H, Keogh J, Barnes M, and McGuigan M. Effects and mechanisms of tapering in maximizing muscular strength. <i>Strength &amp; Conditioning Journal</i> 37(2): 72-83, 2015.	HP 85% MM 5% JK 5% MB 5%
Four	Pritchard H, Tod D, Barnes M, Keogh J, and McGuigan M. Tapering practices of New Zealand's elite raw powerlifters. <i>Journal of Strength &amp; Conditioning Research</i> 30(7): 1796-1804, 2016.	HP 80% MM 5% DT 5% JK 5% MB 5%
Five	Pritchard H, Barnes M, Stewart R, Keogh J, and McGuigan M. Short term training cessation as a method of tapering to improve maximal strength. <i>Journal of Strength &amp; Conditioning Research</i> In Press DOI: 10.1519/JSC.0000000000001803.	HP 80% MM 5% MB 5% RS 5% JK 5%
Appendix B	Pritchard, H., Barnes, M., Keogh, J., & McGuigan, M. The effectiveness of Prilepins chart for strength improvements in recreationally strength trained males. <i>Journal of Strength &amp; Conditioning Research</i> 30(S2): S101, 2016.	HP 80% MB 10% MM 5% JK 5%
Appendix B	Pritchard, H., Barnes, M., Keogh, J., & McGuigan, M. Relationships between 1RM powerlifting competition lifts and common modified and accessory exercises used in training – a pilot study. <i>Journal of Australian Strength and Conditioning</i> 24(6): 48-49, 2016.	HP 85% MM 5% JK 5% MB 5%

**Doctoral Candidate:** Hayden Pritchard 

**Primary Supervisor:** Prof. Michael McGuigan 

**Secondary Supervisor:** A/Prof. Justin Keogh 

**Associate Supervisor:** Dr. Matthew Barnes 

**Contributor:** Dr. David Tod 

**Contributor:** Dr. Robin Stewart 

*All publications are presented as their final peer reviewed manuscripts, using American spelling. Only table, figure and reference numbering has been updated within these chapters to reflect the thesis formatting.*

## LIST OF FIGURES

Figure 1.1: Thesis overview.....	5
Figure 3.1: The Fitness-Fatigue model.....	46
Figure 4.1: Tapering events timeline .....	69
Figure 5.1: Bodyweight changes over time.....	92
Figure 5.2: Vastus Lateralis EMG changes over time.....	93
Figure 5.3: Triceps Brachii EMG changes over time.....	94
Figure 6.1: Normalised Vastus Lateralis EMG over time .....	110
Figure 6.2: Normalised Triceps Brachii EMG over time .....	110

## LIST OF TABLES

Table I.1: Thesis publications .....	IX
Table 2.1: Summary of intensity-related training studies .....	8
Table 2.2: Summary of volume-related training studies .....	17
Table 2.3: Summary of frequency-related training studies .....	24
Table 2.4: Summary of periodisation training studies .....	31
Table 2.5: Prilepin's table.....	42
Table 3.1: Effects of tapering on muscular strength.....	48
Table 3.2: Effects of short-term training cessation on muscular strength .....	55
Table 3.3: Tapering recommendations for maximal strength .....	61
Table 4.1: NZPF elite total standards .....	65
Table 4.2: The questions the participants were asked during the interviews.....	67
Table 4.3: Final training sessions .....	70
Table 4.4: Broad themes and subthemes from the interviews and the sample representativeness .....	71
Table 5.1: Four week training overview.....	86
Table 5.2: Results of performance measures .....	93
Table 5.3: Endocrine and biochemical measures .....	94
Table 6.1: Training programme.....	107
Table 6.2: Taper programmes .....	107
Table 6.3. Performance results .....	109
Table 6.4: Hormonal and biochemical results .....	109
Table B.1: Prilepin's table .....	140
Table B.2: Relationships of powerlift 1RM's to modified & alternative exercises 1RM's .....	142
Table C.1: Isometric bench press CV results .....	143
Table D.1: Reliability of powerlifting performance.....	144
Table D.2: Percentage differences for total result based on placings.....	145

## LIST OF ABBREVIATIONS

AMRAP	as many repetitions as possible
ANOVA	analysis of variance
ASCA	Australian Strength & Conditioning Association
BMS	Ballistic Measurement Systems
BW	bodyweight
CK	creatine kinase
CMJ	countermovement Jump
CSA	cross-sectional area
CV	coefficient of variation
DALDA	daily analysis of life demands in athletes
DUP	daily undulating periodisation
ELISA	enzyme-linked immunosorbent assay
EMG	electromyography
ES	effect size
IBP	isometric bench press
ICC	intra class correlation
IGF	insulin like growth factor
IGFBF	insulin like growth factor binding protein
IPF	International Powerlifting Federation
LVIC	low velocity isokinetic concentric contraction
mRFD	maximal rate of force development
MTP	isometric mid-thigh pull
MVIC	maximal voluntary isometric contraction
NCAA	National Collegiate Athletic Association
NSCA	National Strength & Conditioning Association
NZPF	New Zealand Powerlifting Federation
POMS	profile of mood states
RM	repetition maximum
SD	standard deviation
SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles

TB	triceps brachii
TMD	total mood disturbance
VL	vastus lateralis
WADA	World Anti-Doping Agency

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Rationale

Tapering is a phase of training that aims to enhance performance through reductions in training load that minimise fatigue (97). If a taper is to be effective, it is imperative that it does not produce additional fatigue, or reduce training to such an extent that adaptations are lost and thus performance decreased (111). It is one of the most important phases in a training cycle, enabling athletes to express the results of prior training when it counts, in competition (97). Hence, if performance is to be improved, coaches and athletes should utilise tapering strategies that are proven to be effective.

Maximal strength is the greatest force that can be produced by a muscle, or muscle group (61, 103). Substantial amounts of strength are required in sports where the ability to express force leads directly to improved performance, such as powerlifting, Olympic weightlifting and strongman (53, 103, 182). In fact, strength training for the sport of powerlifting will involve performing the exact competition movements (46, 185). However, athletes in sports with considerable demands on the aerobic system may also enhance performance through improvements in strength (75, 154), and higher level athletes display greater levels of strength than lower level competitors (9). Thus, if maximal strength can be improved and effectively expressed at targeted events, performance could be enhanced in a plethora of sports.

Expressing maximal strength, at a specific event, through an effective taper could improve an athletes' performance. Studies specific to tapering for maximal strength are limited, with a major focus of tapering research exploring aerobically dominant sports (21, 179). Therefore, information regarding effective tapering strategies for maximal strength would provide benefits specifically to strength sports, but also to sports where enhanced strength may aid performance and/or reduce injury risk.

As such, the major aim of this thesis was to determine how strength-trained males can best structure their taper to improve strength performance, and what the mechanisms are behind any performance improvements.

## **1.2 Purpose of Research**

To determine effective tapering strategies, and the underlying mechanisms, several studies were performed. Each study targeted a specific question:

- *Study One:* What do elite strength athletes currently do during their taper prior to important competitions?
- *Study Two:* What is an ideal time frame for enhancing maximal strength through training cessation?
- *Study Three:* Are increases or reductions in training intensity more beneficial when tapering with volume reductions for maximal strength?
- *Studies Two and Three:* What are the mechanisms behind improved performance during both training cessation and tapering?

## **1.3 Significance of the Thesis**

There is currently limited research investigating tapering for maximal strength, particularly in strength trained athletes. The findings from this thesis should assist sports scientists, coaches and athletes in developing effective tapering strategies for strength athletes. Following the literature review, which assisted in the design of strength training programmes as well as provided background of the current knowledge regarding the strength taper, each of the studies aimed to provide specific contributions that could be directly utilised by scientists, coaches and athletes.

Documenting the tapering practices of elite powerlifters will provide valuable knowledge regarding current methods deemed effective by pure strength athletes. Trends within these practices could unveil details that can be applied by other strength athletes such as Strongman and Olympic Weightlifting to enhance their tapering strategies, as well as help avoid common mistakes that can occur with tapering. Similarities in alterations to training volume and intensity during tapering could be

utilised directly by individuals who undertake strength training to guide the changes they make to training prior to competitions. Other information, such as exercise selection and changes to the wider training routine during tapering (e.g. flexibility training and diet), may assist athletes in planning their entire tapering period to be more effective. The findings of this thesis may also be useful to sports scientists in revealing current athlete practices that require scientific validation.

Each training study investigates specific areas of tapering (and peaking) strategies. By directly comparing different periods of training cessation following strength training, athletes and coaches will gain a better understanding of how training cessation can be used to peak for competition. Specifically, whether there is any benefit to shorter or longer periods of training cessation, within the previously recognised effective timeframe (less than one week). Also, by directly comparing increased and decreased training intensity during a volume reduced strength taper, athletes and coaches can be provided with specific guidance of how best to alter training intensity during a strength taper. This information will directly guide how strength athletes and coaches plan training throughout the tapering period, i.e. when training should cease prior to an important event and how to manipulate training intensity immediately prior to this. Through measuring physiological and psychological changes, sports scientists may better understand the underlying mechanisms of effective tapering strategies.

Together these studies will ensure the thesis is able to achieve its major aim in determining how strength-trained athletes can best structure their taper to improve strength performance, and the mechanisms behind any performance improvements. In achieving this aim, sports scientists, coaches and athletes, will gain new knowledge to be utilised in planning, and understanding, the strength taper.

#### **1.4 Structure of the Thesis**

A series of related studies were designed to determine effective tapering strategies in strength-trained men. The first section comprises two literature reviews which provide background on effective strength training methods (Chapter Two) and current knowledge of tapering for maximal strength (Chapter Three). These are followed by a

qualitative study (Chapter Four) which provides insight into the current tapering practices of elite strength athletes, including how and why they undertake a taper prior to important events. Building on the findings of the first three chapters, the first training study (Chapter Five) examined two durations of training cessation for their effects on maximal strength, as well as the underlying mechanisms. The second training study (Chapter Six) investigated whether increased or decreased intensity was more effective during a volume-reduced taper, and the mechanisms underlying these changes. Three of the chapters have been published, or are in press, in peer reviewed journals; Chapter Three has been published in the *Strength & Conditioning Journal* (124), Chapter Four in the *Journal of Strength & Conditioning Research* (126), and Chapter Five is currently in press, also with the *Journal of Strength & Conditioning Research* (125). The overall structure of the thesis is shown in Figure 1.1.

Several appendices follow the general discussion and practical applications. The first are abstracts of published chapters, then posters presented from additional data collection during the thesis. Some notes on reliability then follow, firstly isometric bench press testing methodology and then performance in competitive powerlifters. Additional research outputs during the PhD studies are detailed, and finally ethical approval letters are shown.

## **Tapering Strategies to Enhance Maximal Strength**

### **Chapter One**

**Introduction**

### **Chapter Two**

**Literature Review One – Resistance Training for Maximal Strength: Effective Training Methods and Adaptations**

### **Chapter Three**

**Literature Review Two – Effects and Mechanisms of Tapering in Maximizing Muscular Strength**

*Published in the Strength & Conditioning Journal*

### **Chapter Four**

**Qualitative Study – Tapering Practices of New Zealand's Elite Raw Powerlifters**

*Published in the Journal of Strength & Conditioning Research*

### **Chapter Five**

**Training Study One – Short Term Training Cessation as a Method of Tapering to Improve Maximal Strength**

*In Press with the Journal of Strength & Conditioning Research*

### **Chapter Six**

**Training Study Two – Effects of Varying Intensity during Tapering on Maximal Strength**

### **Chapter Seven**

**General Discussion and Practical Applications**

**Figure 1.1:** Thesis overview

## CHAPTER TWO

### LITERATURE REVIEW ONE: RESISTANCE TRAINING FOR MAXIMAL STRENGTH: EFFECTIVE TRAINING METHODS AND ADAPTATIONS

#### **Preface**

This chapter provides an overview of the literature on training strategies that improve maximal strength and, additionally, acute and chronic adaptations that occur to enhance strength are discussed. A better understanding of how training variables affect training adaptations will assist in designing more effective tapering strategies and help to determine relevant measures to be investigated within subsequent chapters.

#### **Introduction**

Maximal strength is the maximal force that can be produced by a muscle, or a group of muscles (61, 103). It can be enhanced using resistance training, a method of exercise which involves the production of force against an external load. The aim of strength focused resistance training is to produce structural and neurological changes that allow for greater levels of force to be produced by a given muscle, or group of muscles (1). The most common form of resistance training is traditional resistance training using barbells, dumbbells and machine weights; this style of resistance training will be the focus of this chapter.

Training intensity, volume, frequency and periodisation will be discussed in detail with a specific focus on how each of these variables affects the expression of maximal strength, and the adaptations that occur in response to changes in each variable. Other training variables will be briefly mentioned, including rest periods, overreaching, overtraining and detraining.

Where possible, percentage change and effect sizes (ES) were calculated from data within the reviewed literature (47). Alternatively, if available, values from the studies were reported.

## **2.1 Intensity of Training**

Training intensity is the load or weight lifted. In this chapter, relative intensity, or percentage of one repetition maximum (1RM) lifted will be the focus. Training intensity has a direct impact on the number of repetitions able to be performed during a single set, and will therefore impact the volume during a training session (61).

Training intensity is the most specific training variable to maximal strength, as when intensity is higher the load is greater – closer to maximal effort. Table 2.1 shows a summary of intensity-related training studies.

### **2.1.1 The Effects of Training Intensity on Maximal Strength**

Some of the earlier studies were carried out by Berger (16, 17) who investigated a combination of different intensities of training, over a 12-week period with recreationally trained university students, with no control of training volume. Bench press was trained three times per week with one to three sets, for two, six or 10 repetitions. The results showed three sets of six repetitions to be most effective at enhancing strength (16). The second 12-week training study split participants into groups performing a set of repetitions between two to 12 repetitions on the bench press. The optimum was between three and nine repetitions, for one set, to enhance strength (17). A further study by Berger (18) trained participants three days per week for six sets of 2RM, three sets of 6RM, or three sets of 10RM. This study showed no significant differences among groups for bench press strength. O'Shea (117) utilised three sets of the back squat at three differing loads with recreationally trained males. No training load, from 2-10RM, was found to be more effective at increasing either dynamic 1RM or static strength. Anderson & Kearney (6) compared a greater range of training intensities in college students. The 6-8RM group improved maximal strength 20% in comparison to 8% and 5% for the 30-40RM and 100-150RM groups, respectively. Choi et al.'s (29) higher intensity group (90% 1RM) had enhanced maximal strength in comparison to the lower intensity group. Together these studies indicate that intensities allowing for 10 or less repetitions per set are most effective at enhancing strength. However, the large range of effective RM loads (2-10RM) may be explained by recruitment of untrained or novice weight trainers.

**Table 2.1:** Summary of intensity-related training studies

Author (year)	Participants and training history	Training performed by each group: sets x reps	Volume controlled?	Performance changes (% change, ES) ↑↑ = significant change ↑ = non-significant change
Berger (1962) (16)	177 recreationally trained males	G1 (n = 19): 1 x 2RM G3 (n = 19): 1 x 10RM G5 (n = 20): 2 x 6RM G7 (n = 18): 3 x 2RM G9 (n = 19): 3 x 10RM  G2 (n = 22): 1 x 6RM G4 (n = 18): 2 x 2RM G6 (n = 21): 2 x 10RM G8 (n = 21): 3 x 6RM  Three days per week for 12-weeks utilising the BP.	No	G1 ↑↑ 1RM BP (19.6%, 1.16)      G2 ↑↑ 1RM BP (24.8%, 1.13) G3 ↑↑ 1RM BP (21.6%, 1.63)      G4 ↑↑ 1RM BP (16.8%, 1.17) G5 ↑↑ 1RM BP (23.0%, 1.23)      G6 ↑↑ 1RM BP (25.5%, 1.29) G7 ↑↑ 1RM BP (24.8%, 1.38)      G8 ↑↑ 1RM BP (30.2%, 1.74) G9 ↑↑ 1RM BP (24.0%, 1.27)  G8 showed the greatest changes.
Berger (1962) (17)	199 recreationally trained males	G1 (n = 33): 1 x 2RM G3 (n = 34): 1 x 6RM G5 (n = 32): 1 x 10 RM  G2 (n = 35): 1 x 4RM G4 (n = 34): 1 x 8RM G6 (n = 31): 1 x 12RM  Three days per week for 12-weeks utilising the BP.	No	G2, G3, and G4 improved 1RM BP significantly more than G1; G2 and G4 improved 1RM BP significantly more than G5; G4 improved 1RM BP significantly more than G6.
Berger (1963) (18)	48 recreationally trained males	G1 (n = 16): 6 x 2RM G3 (n = 16): 3 x 10RM  G2 (n = 16): 3 x 6RM  Three days per week for nine-weeks utilising the BP.	No	All groups ↑↑ 1RM BP, no differences between groups.
O'Shea (1966) (117)	30 recreationally trained males	G1 (n = 10): 3 x 9-10RM G3 (n = 10): 3 x 2-3RM  G2 (n = 10): 3 x 5-6RM  Three days per week, for six-weeks utilising the SQ.	No	G1 ↑↑ 1RM SQ (24.9%) & MVIC Knee Ext (21.2%) G2 ↑↑ 1RM SQ (26.8%) & MVIC Knee Ext (15.5%) G3 ↑↑ 1RM SQ (21.9%) & MVIC Knee Ext (23.2%)  No significant differences between groups.
Anderson & Kearny (1982) (6)	43 untrained males	G1 (n = 15): 3 x 6-8RM G3 (n = 12): 1 x 100-150RM  G2 (n = 16): 2 x 30-40RM  Three days per week for nine-weeks utilising the BP.	No	G1 ↑↑ 1RM BP (20.2%, 2.92) G2 ↑↑ 1RM BP (8.2%, 1.16) G3 ↑↑ 1RM BP (4.9%, 0.65)  G1 improved significantly more than G2 or G3.

Choi et al. (1988) (29)	11 untrained males	G1 (n = 5): 5 x AMRAP at 90% 1RM G2 (n = 6): 9 x AMRAP at 80-60-50%, 70-50-40%, and 60-50-40% 1RM  Training occurred two days per week for eight-weeks utilising the Knee Ext	No	G1 ↑↑ 1RM Knee Ext (43.2%, 2.43), MVIC Knee Ext (36.3%, 2.81), and LVIC Knee Ext (33.0%, 1.73) G2 ↑↑ 1RM Knee Ext (34.8%, 2.81), MVIC Knee Ext (19.3%, 0.95), and LVIC Knee Ext (25.8%, 2.90)  G2 improved significantly more in the MVIC Knee Ext.
Chestnut & Docherty (1999) (27)	24 untrained males (five as controls)	G1 (n = 10) = 6 x AMRAP at 4RM (≈85% 1RM) G2 (n = 9) = 3 x AMRAP at 10RM (≈70% 1RM)  Three days per week for 10-weeks utilising four upper body exercises. Three further upper body exercises were trained for one (G2) or two (G1) sets at the same respective intensities.	Yes	G1 ↑↑ 1RM CGBP & 1RM Bicep Curl G2 ↑↑ 1RM CGBP & 1RM Bicep Curl  No significant differences between groups.
Campos et al. (2002) (25)	32 untrained males (five as controls)	G1 (n = 9): 4 x 3-5RM      G2 (n = 11): 3 x 9-11RM G3 (n = 7): 2 x 20-28RM  Two days per week for the first four weeks, three days per week for final four weeks, eight weeks in total. SQ, LP and Knee Ext were trained.	Yes	G1 ↑↑ 1RM SQ, LP & Knee Ext G2 ↑↑ 1RM SQ, LP & Knee Ext G3 ↑↑ 1RM SQ, LP & Knee Ext  G1 improved significantly more in 1RM SQ & LP than G2 or G3; G1 improved more than G3 in 1RM Knee Ext.
Willoughby (1993) (178)	92 weight-trained males (1RM BP ≥ 1.2 x BW; 1RM SQ ≥ 1.5 x BW; 23 as controls)	G1 (n = 23): 5 x 10RM (78.9% 1RM) G2 (n = 23): 6 x 8RM (83.3% 1RM) G3 (n = 23): Four week periodised blocks, intensities from 10RM to 4RM  Three days per week of SQ & BP for sixteen weeks.	Yes W1-8 No W9-16	G1 ↑↑ 1RM SQ & BP G2 ↑↑ 1RM SQ & BP G3 ↑↑ 1RM SQ & BP  G3 was significantly higher than all groups after eight weeks in the 1RM BP, and in both exercises by week 16.
Harris et al. (2000) (70)	42 weight-trained males (1RM SQ ≥ 1.4 x BW)	G1 (n = 13): 5 x 5 at 80% 1RM G2 (n = 16): 5 x 5 at 30-45% 1RM G3 (n = 13): Day One 5 x 5 at 80% 1RM Day Two 5 x 5 at 30-60% 1RM  Four times per week, two training days performed two times per week, for nine weeks. Each day was full body	No	G1 ↑↑ 1RM SQ (9.8%, 1.73), ¼ SQ (33.9%, 6.52), and MTP (33.7%, 8.52) G2 ↑ 1RM SQ (3.6%, 0.54) ↑↑ 1RM ¼ SQ (15.5%, 3.32), and 1RM MTP (22.6%, 4.77) G3 ↑↑ 1RM SQ (11.6%, 1.35), ¼ SQ (37.7%, 5.99), and MTP (39.9%, 9.81)  G3 improved significantly more than G2 in all 1RM's, G1 improved significantly more than G2 in the 1RM ¼ squat.

Schoenfeld et al. (2014) (143)	20 weight-trained males (≥ three days per week, for ≥ one year)	G1 (n = 8): 7 x 3RM G2 (n = 9): 3 x 10RM  For eight-weeks. A total of nine exercises were trained across three days of the week. G1 trained full body each day, while G2 trained one area of the body each training day.	Yes	G1 ↑↑ 1RM SQ (34.8%, 0.74) & BP (10.6%, 0.46) G2 ↑↑ 1RM SQ (18.9%, 0.64) & BP (8.2%, 0.41)  After adjusting for baseline values, it was found that G1 improved significantly more in 1RM BP than G2.
AMRAP = As many repetitions as possible; BP = Bench press; BW = Bodyweight CG = Close grip; ES = Effect size; Ext. = Extension; G = Group; LP = Leg press; LVIC = Low velocity isokinetic concentric contraction; MTP = Mid-thigh pull; MVIC = Maximal voluntary isometric contraction; RM = repetition maximum; SQ = Back squat; ↓ indicates decreased; ↑ indicates increased.				

*N.B. Effect sizes and percentage changes were calculated wherever sufficient data could be obtained in manuscripts, otherwise reported values were used (if available).*

Other studies have had greater control over training volume, while still recruiting untrained participants. Chestnut and Docherty (27) utilised a more comprehensive training programme of the upper body utilising predominately 4RM or 10RM loads with similar training volume between groups. Both groups showed significant improvements in strength of the forearm extensors and flexors, with no significant differences between groups. Campos et al. (25) had untrained participants train with low (3-5RM), intermediate group (9-11RM) or high repetitions (20-28RM). Volume was not significantly different between groups. All groups showed significantly improved 1RM of the three exercises. However, the low repetition group showed significantly greater improvements in the leg press and squat in comparison to all other groups, and for the leg extension in comparison to the high repetition and control groups. These volume controlled studies show similar results to the non-volume controlled studies, that lower repetitions ( $\approx 10$  or less) results in greater strength improvements than higher repetition ranges in previously untrained, or novice, participants.

Researchers have also investigated the effects of different training intensities on strength in trained participants without control of training volume (70, 178). Willoughby (178) compared a periodised training approach to two non-periodised training approaches over 16-weeks with previously weight-trained individuals. The two non-periodised groups showed equal, statistically significant, improvements in strength. However, the periodised training (which progressed to higher intensities) showed statistically significant improvements compared to the two non-periodised groups. This result shows that varying the intensity of training may be more effective than consistent training (periodisation is discussed in section 2.4), and that training at higher intensities ( $\leq 6RM$ ) may result in greater strength improvements compared to lower intensities (8-10RM) with previously trained participants. Harris et al. (70) trained participants with 80-85% 1RM (heavy),  $\approx 30-45\%$  1RM (power), or a combination of these loads. All groups improved in the quarter squat 1RM and mid-thigh (block) pull, however, the heavy training group showed significant improvements in the squat 1RM, but the power group did not (9.8% vs 3.6%). The combined group also showed significant improvements (11.6%). This indicated that exposure to heavier loads produced greater strength gains than light loads alone in trained participants.

Schoenfeld et al. (143) conducted a study where volume was controlled using trained participants. A strength group performed seven sets of three repetitions, while a hypertrophy group performed three sets of 10 repetitions (8-12RM). The strength group trained using a full body routine each day, whereas the hypertrophy group performed a body part split routine (of the same exercises). Both groups enhanced 1RM bench press and back squat. However, when adjusted for baseline values, the strength group had significantly greater improvements in bench press 1RM and a trend for greater improvements in back squat 1RM. Indicating that even when controlled for training volume, higher intensity loads are more effective at enhancing strength in trained participants.

Meta-analyses on training intensity have been performed. Rhea et al. (133) found that for untrained participants a mean intensity of 60% 1RM induces maximal gains, while for trained participants 80% 1RM was most effective. Similarly, Peterson et al. (121) stated that athletes who train with an average of 85% 1RM show greatest improvements. A literature review by Hartmann et al. (72) also stated the need for trained athletes to regularly train with loads exceeding 80% 1RM to improve both strength and power. Together these reviews show the importance of utilising high intensity training (>80% 1RM) to elicit improvements in maximal strength when participants have previous training experience.

When taken together these data show that, in trained participants, higher intensities ( $\geq 80\%$ ) and less repetitions ( $\leq 6$ ) per set may be more beneficial than moderate or light loads ( $\leq 80\%$ ) for higher repetitions ( $\geq 8$ ) over a moderate training period ( $\leq 16$  weeks) (70, 143, 178). Whereas, in previously untrained participants moderate loads ( $\approx 70\%$ ) and moderate repetition ranges ( $\approx 10$ ) may be as beneficial as heavier training (17, 27).

### **2.1.2 Adaptations to Training Intensity**

Muscular hypertrophy results in an increase in contractile units within a muscle, and thus may enhance strength. Chestnut and Docherty (27) showed significantly increased flexed-arm girth for both 4RM and 10RM training groups, with no differences seen between groups. Similarly, Schoenfeld et al. (143) showed increased muscle thickness

(biceps brachii), with no difference between 3RM or 10RM training groups when training volume was equal. Campos et al. (25) showed that low repetition (3-5RM) and intermediate repetition (9-11RM) training in untrained participants resulted in hypertrophy of all fibre types (I, IIA and IIX). This change was not seen in the high repetition (20-28RM) group. Type I fibre area increased by  $\approx 12.5\%$ , type IIA  $\approx 19.5\%$  and type IIX  $\approx 26.0\%$  in these two groups. All training groups also displayed a change from IIB to IIAB, with a corresponding change in myosin heavy chain (MHC) isoforms (decreased MHCIIX and increased MHCIIA). Earlier work by Häkkinen et al. (64) also showed increases in fibre areas of fast and slow twitch fibres following 16-weeks of training at 80-120% of concentric 1RM in weight-trained participants ( $n = 14$ ), this change was noted to occur primarily in the second half of the training period. Aagaard et al. (2) also showed increased muscle cross-sectional area (CSA), with significantly increased type II fibre size following 14-weeks of heavy lower body resistance training. The mechanical strain on the musculature from the load being lifted must therefore cause a stress resulting in adaptations to the size, and type, of fibres to allow for enhanced strength.

Studies have demonstrated improvements in strength relative to, or in the absence of changes in, muscle size (29, 70). Choi et al. (29) showed that higher repetitions with a lower intensity produced greater improvement in CSA of the quadriceps than training at a higher intensity with fewer repetitions did. However, the higher intensity group showed greater levels of strength per unit CSA, suggesting a greater ability to utilise the available muscle mass. Harris et al. (70) also showed that improvements in strength can be made without significant changes in lean body mass (i.e. no additional muscle mass) in previously trained participants. As such, a change in maximal strength is not subject solely to the amount of muscle mass available but also the ability to utilise it. These studies (29, 70) did not measure any changes in fibre types, muscle architecture, or neural activation which may affect the ability to produce high force.

Enhanced neural activation has been observed following strength training at a high intensity. Häkkinen and Komi (65) saw increased neural activation (via electromyography, EMG) of trained muscles following 16-weeks of training at 80-120% of concentric 1RM in 14 recreationally trained participants. This change was observed

to a greater degree during the first half of the training period. Häkkinen et al. (66) also tracked 13 elite weightlifters over a full training year. During the four months of the year with the lowest average training intensity ( $77.1 \pm 2.0\%$  1RM), there was a significant reduction in neural activation, whilst the final four-month period of the year with slightly higher average training intensity ( $79.1 \pm 3.0\%$  1RM) had the greatest increases in neural activation. This highlighted the importance of training intensity in enhancing neural activation. Newton et al. (116) showed a general trend towards increased quantity of EMG activity in the working muscles during bench throws of increasing load. They stated that more motor units would be required (fast and slow) due to the requirement of greater force production to overcome the heavier loads (116). Given the acute effect of higher training loads is to require more EMG activation, it would be expected that chronic exposure to this in training would result in a greater ability to activate the muscle. In fact, Seynnes et al. (146) showed that within 35 days of heavy resistance training of the quadriceps, previously untrained participants had enhanced EMG activity by 35% and also had enhanced quadriceps strength. Therefore, the acute stress of training with heavy loads can produce a chronic adaptation of enhanced neural activation, leading to enhanced strength.

Acute endocrine responses may play a role in chronic hypertrophy throughout a given training period (92). Raastad et al. (128) showed that the acute increase in both testosterone and cortisol, in strength-trained individuals, was higher when the same volume (three sets of three) was performed at 3RM compared to 6RM loads on squat and front squat (alongside three sets of six repetitions at 6RM on the knee extension). In contrast, growth hormone showed only moderate increases, and large inter-individual variations in responses. However, Schwab et al. (144) found that both four sets of six repetitions at 90-95% of 6RM produced a similar testosterone response to four sets of 9-10 repetitions at 60-65% of 6RM. Crewther et al. (39) also demonstrated that the salivary testosterone and cortisol response was greater in a higher repetition (10 sets of 10 repetitions at moderate weight, 75% 1RM) compared to volume controlled power (eight sets of six at 45% 1RM) or strength (six sets of four at 88% 1RM) training session. This indicates that the intensity of training may be less important than the total volume of training in terms of an acute endocrine response, but when volume is equal higher intensities may produce larger endocrine responses.

The effect of acute hormonal responses on chronic hypertrophy should be interpreted with caution. West and Philips (175) debated that acute changes in growth hormone and testosterone may not be direct stimulators of muscular hypertrophy, but perhaps play a role in fuel mobilisation. They showed increases in LBM, following 12-weeks of whole body resistance training with a large sample size ( $n = 56$ ), to be correlated with acute increases in cortisol but not growth hormone or testosterone (176). However, growth hormone was positively associated with increases in Type I and Type II fibre CSA areas. Cortisol was also correlated with increases in Type II CSA. Schoenfeld et al. (139) reviewed literature in this area and concluded that if there is an effect of the acute hormonal response, it is likely only a small effect. The lack of research in trained individuals was noted, this area requires further investigation given that larger acute hormonal responses occur in strength-trained individuals (165). Thus, the effects of acute hormonal responses on chronic muscular hypertrophy are not conclusive. Further investigation, especially in trained individuals, is warranted.

Muscle architecture has also been shown to play a role in enhanced maximal strength (2). Aagaard et al. (2) showed that 14-weeks of training, with both compound and isolation exercises for the lower body, progressing from moderate (10-12RM) to heavy (3RM) loads (with volume held constant throughout) produced significant changes in muscle architecture in previously untrained participants. Their results showed increased fibre pennation angle of the quadriceps resulting in greater physiological (functional) CSA following this heavy resistance training. Seynnes et al. (146) also showed increased fascicle length and quadriceps pennation angle following five weeks of resistance training. Blazevich et al. (19) showed that, in trained participants, five weeks of strength training combined with sprint jump training resulted in increased fascicle angle, while fascicle length remained unchanged; in contrast, performing solely sprint/jump training decreased fascicle angle and increased fascicle length. Such a finding shows adaptations occur in relation to both loading and speed of movement. However, in untrained participants utilising isokinetic training Blazevich et al. (20) saw enhanced strength in the absence of architectural changes, indicating the importance of neural adaptations in the early stages of training. It appears that resistance training can produce changes in muscle architecture which assist maximal strength production; however, no studies have directly compared different strength training intensities.

It has been demonstrated that the two primary adaptations resulting in maximal strength increases are related to muscle size and neural activation (25, 146). Training intensity appears to have a direct effect on each of these factors, however, these changes are also under the influence of training volume.

## **2.2 Training Volume**

Training volume can be defined as repetition volume (sets multiplied by repetitions) or volume load (repetition volume multiplied by the weight lifted). It can be calculated for a training session, a week of training, or even a block of training (61). Given that intensity of resistance training dictates repetitions within a set, the focus of this section will be on the number of sets performed during a session, and the effects this will have on maximal strength. Where a study's methodology has previously been discussed, only the results pertaining to training volume will be described. Table 2.2 shows a summary of volume-related training studies.

### **2.2.1 The Effects of Training Volume on Maximal Strength**

Many studies have investigated the effects of training volume on strength improvements, showing multiple sets to be superior in comparison to single sets (16, 101, 131). Berger's (16) work found three sets produced greater improvements in strength in comparison to one or two sets in untrained men, and that three sets of six repetitions was most effective. Rhea et al. (131) had previously trained participants perform one or three sets of bench press and leg press. Both protocols elicited significant strength gains, however, the three-set protocol was found to be more effective than one set. Marshall et al. (101) had resistance trained participants perform six weeks of squat training to volitional exhaustion at 80% 1RM for one, four or eight sets, followed by the same peaking plan. The eight-set group had significantly greater 1RM squat strength than the one-set group. At no point during the training period were there any significant differences between the four-set and eight-set groups, or the four-set and one-set groups. Multiple sets appear to have a greater potential to enhance strength than single sets, but there appears to be a threshold above which there are no additional strength benefits.

**Table 2.2:** Summary of volume-related training studies

Author (year)	Participants and training history	Training performed by each group: sets x reps	Intensity controlled?	Notable performance changes (% change, ES)  ↑↑ = significant change ↑ = non-significant change
Berger (1962) (16)	177 recreationally trained males	G1 (n = 19): 1 x 2RM G2 (n = 22): 1 x 6RM G3 (n = 19): 1 x 10RM G4 (n = 18): 2 x 2RM G5 (n = 20): 2 x 6RM G6 (n = 21): 2 x 10RM G7 (n = 18): 3 x 2RM G8 (n = 21): 3 x 6RM G9 (n = 19): 3 x 10RM  Three days per week for 12-weeks utilising the BP	No	G1 ↑↑ (19.6%, 1.16)    G2 ↑↑ (24.8%, 1.13) G3 ↑↑ (21.6%, 1.63)    G4 ↑↑ (16.8%, 1.17) G5 ↑↑ (23.0%, 1.23)    G6 ↑↑ (25.5%, 1.29) G7 ↑↑ (24.8%, 1.38)    G8 ↑↑ (30.2%, 1.74) G9 ↑↑ (24.0%, 1.27)  G8 showed the greatest changes.
Rhea et al. (2002) (131)	16 recreationally trained males (≥ two days per week, for ≥ two years)	G1 (n = 8): Day One 1 x 8-10RM, Day Two 1 x 6-8RM, and Day Three 1 x 4-6RM G2 (n = 8): Day One 3 x 8-10RM, Day Two 3 x 6-8RM, and Day Three 3 x 4-6RM  For 12-weeks utilising the LP and BP, one week break from week's five to six. G1 performed a set of unrelated exercises (8-12RM) each day, G2 only if time.	Yes	G1 ↑↑ 1RM LP (25.3%, 1.36) and BP (19.5%, 0.60) G2 ↑↑ 1RM LP (52.1%, 1.78) and BP (28.1%, 1.20)  G2 improved 1RM LP significantly more than G1.
Marshall et al. (2011) (101)	32 weight-trained males (≥ 1.3 x BW 1RM SQ; ≥ two days a week for ≥ two years)	G1 (n = 11): 1 x AMRAP at 80% 1RM G2 (n = 11): 4 x AMRAP at 80% 1RM G2 (n = 10): 8 x AMRAP at 80% 1RM  For six-weeks, a standard upper body training regime continued throughout, while the squat was trained as above. Day one: Chest, shoulders and arms; Day two: Back and squat. Each day was repeated twice per week.	Yes	G1 ↑↑ 1RM SQ (11.7%) G2 ↑↑ 1RM SQ (13.9%) G3 ↑↑ 1RM SQ (22.8%)  G3 improved 1RM SQ significantly more than G1.
González-Badillo et al. (2005) (57)	51 junior male weightlifters (≥ three years)	G1 (n = 16): Performed 1,923 total repetitions over the training period G2 (n = 17): Performed 2,481 total repetitions over the training period G3 (n = 18): Performed 3,030 total repetitions over the training period  For 10-weeks a variety of weightlifting exercises were trained at 60-100% 1RM for one to six repetitions per set (periodised), on four to five days a week.	Yes	G1 ↑↑ 1 RM Clean and Jerk (3.7%) and SQ (4.6%) G2 ↑↑ 1RM Snatch (6.1%), Clean and Jerk (3.7%) and SQ (4.2%) G3 ↑↑ 1 RM Clean and Jerk (3.0%) and SQ (4.8%)  G2 improved 1RM Snatch significantly more than G1.

Amirthalingam et al. (2016) (3)	19 weight-trained males (≥ three resistance training sessions per week, for ≥ one year)	G1 (n = 9): 5 x 10 at ≈60% 1RM G2 (n = 10): 10 x 10 at ≈60% 1RM  For six-weeks. The prescriptions above were for two major exercises each day, three assistance exercises were also performed for three to four sets of 10 repetitions (or AMRAP) at 60-80% 1RM for both groups. Three days per week, a split routine.	Yes	G1 ↑↑ 1RM LP (8.1%, 0.49), Lat-Pull Down (15.0%, 0.62), and BP (15.4%, 0.61) G2 ↑↑ 1RM LP (4.2%, 0.33), Lat-Pull Down (4.1%, 0.27), and BP (5.0%, 0.29)  G1 improved 1RM LP and Lat-Pull Down significantly more than G2
Fry et al. (1994) (51)	17 weight-trained males (≥ 1.5 x BW 1RM SQ)	G1 (n = 11): 10 x 1 at 100% 1RM – six days per week on a Machine SQ G2 (n = 6): 3 x 5 at 50% 1RM – one day per week on a Machine SQ  For two-weeks. Upper body training continued as per normal for each group.	No	G1 decreased 1RM Machine SQ significantly more (-12.2 kg) than G2 (-1.1 kg). G1 was significantly less for both MVIC and LVIC Knee Ext than G2 post-training.
Fry et al. (1994) (52)	9 weight-trained males (≥ 1.2 x BW 1RM SQ)	G1 (n = 5): 8 x 1 at 95% 1RM – six days per week on a Machine SQ G2 (n = 4): 3 x 5 at 70% of BW – two days per week on a Machine SQ  For three weeks. It wasn't specified if upper body training continued.	No	G1 ↑↑ 1RM Machine SQ (6.6%), and ↓↓ LVIC Knee Ext (-7.2%) G2 ↑↑ 1RM Machine SQ (6.0%)  No significant differences between groups.
Starkey et al. (1996) (151)	48 untrained participants (21 males, 27 females; 10 as controls)	G1 (n = 18): 1 x 8-12RM G2 (n = 20): 1 x 8-12RM  Three days per week for 14-weeks, utilising knee extension and flexion exercises.	Yes	Both groups significantly improved MVIC Knee Ext and Flex at almost all angles (seven angles were measured). One angle showed a significant difference between groups, favouring G1, when pre-training values were used as a covariate. No other differences were found.
Ostrowski et al (1997) (118)	35 weight-trained males (≥ 1.3 x BW 1RM SQ; ≥ 1.0 x BW 1RM BP)	G1 (n = 9): Three sets per muscle group per week G2 (n = 9): Six sets per muscle group per week. G3 (n = 9): 12 sets per muscle group per week.  Four days per week, for 10-weeks. Utilising a periodised split routine with six exercises trained per day, intensities ranging from 7-12RM.	Yes	G1 ↑ 1RM SQ (7.5%, 0.36) and BP (4.0%, 0.32) G2 ↑ 1RM SQ (5.5%, 0.36) and BP (5.0%, 0.48) G3 ↑ 1RM SQ (11.6%, 0.75) and BP (1.9%, 0.16)  No significant differences between groups. A significant time effect was found when groups were combined.
AMRAP = As many repetitions as possible; BP = Bench press; BW = Bodyweight; ES = Effect size; Ext. = Extension; G = Group; LP = Leg press; LVIC = Low velocity isokinetic concentric contraction; RM = repetition maximum; SQ = Back squat; ↓ indicates decreased; ↑ indicates increased.				

*N.B. Effect sizes and percentage changes were calculated wherever sufficient data could be obtained in manuscripts, otherwise reported values were used (if available).*

Adding more volume does not always result in enhanced strength. Gonzalez-Badillo et al. (57) had experienced junior weightlifters train the snatch, clean and jerk and squat for 10-weeks with low volume, moderate volume or high volume. All groups trained with the same relative intensity. The moderate volume group showed significant improvements for all three exercises, while the higher and lower volume groups showed significant improvements for only two out of three exercises (clean and jerk, and the squat). The mean ES for the Olympic lifts was higher for the moderate volume group (0.42) compared to the other two groups (both 0.16). Amirthalingam et al. (3) found that 10 sets of 10 was no more effective than five sets of 10 in trained participants. Improvements were greater in bench press and latissimus dorsi pull down 1RM for the five-set group, while both groups showed similar improvement in the 1RM leg press. Fry et al. (51) planned an intentionally excessive two-week training regime (10 maximal effort singles, six days a week) using well trained participants. The high volume high intensity group showed significant decrements in 1RM performance on the squat machine, while their control group remained unchanged. Another study by the same group using a training protocol of similar intensity (95% 1RM), but fewer sets on five days per week ( $\approx 40\%$  less volume) enhanced 1RM strength (52). Clearly, more volume is not always better, especially with heavy loads.

The studies discussed thus far have shown benefits of multiple sets in comparison to a single set, however, not all research supports this consensus (118, 151). Starkey et al. (151) showed no significant differences in isometric strength improvements between one or three sets of training. Ostrowski et al. (118) found significant improvements in 1RM squat and bench press for all groups combined after training muscle groups for three, six or 12 sets a week. However, there were no differences between groups. It should be noted that each of the above training studies utilised training intensities lower than 6RM (i.e. 7RM or more), which may affect the specificity of the training for enhancing maximal strength.

Several meta-analyses have been performed on the effect of resistance training volume and maximal strength (93, 132, 133, 183). Rhea et al. (132) found an overall ES = 0.28 in favour of three sets over one set for the eligible studies reviewed. This ES rose to ES = 0.70 when only studies controlling training intensity and variation were

included. Trained individuals had a greater strength increase (ES = 0.55) in comparison to untrained (ES = 0.23) when performing multiple sets. A second meta-analysis by Rhea et al. (133) showed that four sets per muscle group elicits maximal strength gains in both trained and untrained individuals, with untrained individuals experiencing greater strength improvements across all numbers of sets analysed. Wolfe et al. (183) found multiple set programmes to be superior when training for longer durations (i.e. more weeks of training). Trained individuals demonstrated greater gains in strength on multiple set programmes, while untrained individuals achieve similar gains on single and multiple set programmes. Krieger (93) concluded that two to three sets per exercise was associated with 46% greater improvements in maximal strength than one set, and that four to six sets provided no additional benefit over two to three sets. One set had an ES = 0.54, two to three sets had an ES = 0.79, and four to six sets had an ES = 0.89. No differences were observed between trained and untrained individuals in this study.

Although there is some debate within the literature, there are several trends based on the training status of individuals. For trained individuals, multiple sets generally produce greater gains in strength when intensity is sufficient (57, 101, 131). While for untrained individuals in the initial stages of strength training, single sets may provide similar benefits to multiple set regimes (132, 183). However, performing too much volume can be less effective (57) or detrimental (51) to performance, so caution should be applied in prescribing large numbers of high intensity sets. A periodised approach may also provide additional benefits (57, 131) (see section 2.4).

### **2.2.2 Adaptations to Training Volume**

Limited studies have investigated the chronic adaptations that occur due to training volume differences. However, one of the primary adaptations to higher volume training is said to be greater hypertrophy (61), and this has been well investigated. Many studies support this hypothesis (94, 101, 118), while not all agree (151).

Starkey et al. (151) showed similar increases for muscle thickness measures of the quadriceps and hamstrings whether one or three sets of knee extension and knee

flexion were performed for 14-weeks in previously untrained participants. Ostrowski and colleagues (118) showed no significant benefit of higher volume to hypertrophy in intensity controlled training in previously trained participants however a greater change in bicep thickness was seen in the medium (4.7%) and high (4.8%) volume groups compared to the low (2.3%) volume group. Conversely, Marshall et al. (101) found that body mass increased (while body fat decreased) in an eight-set training group, while BW remained unchanged (with lower body fat) in the one and four-set groups. These changes in body mass and body fat were suggestive of greater lean mass gains in the higher volume group. In a meta-analysis Krieger (94) found that training with multiple sets produced a significantly greater effect on hypertrophy in comparison to single sets (difference in ES = 0.11). There was also a trend for two to three sets per exercise to have a greater ES than one set (difference in ES = 0.09), and for four to six sets per exercise to have a greater ES than one set (difference in ES = 0.20). ES's increased as the number of sets per exercise increased, one set (ES = 0.24), two to three sets (ES = 0.34) and four to six sets (ES = 0.44). Multiple sets of resistance training can produce greater effects on hypertrophy than a single set of resistance training.

Acute changes in the endocrine system may play a role in chronic hypertrophy and these responses can be heavily influenced by training volume (92). Craig and Kang (37) showed total volume, when two back squat sets were performed to failure (first set at 75% 1RM, then second set at 90% 1RM) with a three minute rest between sets, enhanced growth hormone to a much larger extent than one 15-second maximum repetition set at either intensity on its own. Gotshalk et al. (58) also showed the superiority of multiple (three) sets in comparison to one set for acutely increasing levels of growth hormone, as well as testosterone, following heavy (10RM) resistance exercise (eight exercises). Ratamess et al. (129) showed the testosterone response to exercise was greater following six sets of 10 repetitions at 80-85% 1RM load in comparison to one set. They also found that androgen receptor content is initially downregulated (an hour post-exercise) following higher volume training, but hypothesised this initial downregulation must be followed by a later upregulation. Research has shown upregulation of androgen receptor content following acute resistance exercise (11) and in strength-trained populations (87). In fact, it appears

that the acute testosterone response may potentiate muscle androgen receptor content (150). A greater number of androgen receptors within a muscle will increase the sensitivity of the tissue to testosterone and may therefore enhance its hypertrophic effect (87). The acute endocrine response is sensitive to training volume and greater volume appears to result in a more anabolic environment post-exercise. Again, such acute hormonal results should be interpreted with caution given the inconclusive data of acute hormonal changes on chronic muscular hypertrophy (139).

Limited research has compared the chronic effects of training volume on the endocrine system or neuromuscular changes. Although Ostrowski et al. (118) saw no significant changes in resting endocrine measures following 10-weeks of resistance training with low, medium or high volume (118), ES's suggested a possible testosterone to cortisol ratio increase in the low and moderate volume groups. There was also a decrease in the testosterone to cortisol ratio for the high-volume group, indicating a potential overreaching stress, while the moderate and low volume groups were in a more anabolic state. Other studies have also shown that excessive training volume may induce overtraining (51) which is discussed in section 2.5.2. Marshall et al. (101) found no changes in quadriceps EMG, indicating no change in activation of this muscle group during their study using trained participants. Further investigation is required to determine neuromuscular changes involved in enhancing strength following training with different volumes.

The major positive effect of training volume appears to be on muscle hypertrophy. Greater training volumes will result in greater hypertrophy (93), however, there is an upper limit and above this overreaching and potentially overtraining may result (51). This change appears to be due to acute changes in the endocrine system (58). Other potential neuromuscular changes require further investigation in controlled training studies.

### **2.3 Training Frequency**

Frequency of training indicates how often training is performed in a given time period (61). This is usually weekly and may also be stipulated in terms of training frequency of

a muscle group or exercise. The number of training sessions performed per week can also play a role in determining total weekly training volume, as volume will be accumulated per training session, and therefore training frequency will directly influence training volume (61). Table 2.3 outlines a summary of training studies investigating the effect of altering training frequency on muscle performance.

### **2.3.1 Effects of Training Frequency on Maximal Strength**

Comparisons have been made between different training frequencies within a week, with little or no control over total training volume (22, 77). Braith et al. (22) showed that in previously untrained males and females training three days per week was superior to training for two days per week with one set of knee extensions at 7-10RM. However, the lower frequency training group still attained  $\approx 80\%$  of strength gains of the higher frequency group. Hoffman et al. (77) investigated the effects of self-selected frequency of training on strength in football players. Training five days per week significantly increased bench press strength, and four, five and six days per week groups significantly increased squat strength. Interestingly, it was also noted that the larger and stronger athletes tended to select the greater number of training days per week (e.g. the six-day group had an average weight of 112.3 kg, compared to 80.3 kg in the three-day group), even though they had similar training experience. The results of these studies indicate that higher training frequencies may be more effective than lower frequency, but, without volume control it is difficult to conclude whether this change is due to changes in training volume or because of frequency alone. However, increasing training frequency could indeed be used as a training strategy to achieve increases in total training volume, and thus achieve volume associated gains in maximal strength.

**Table 2.3:** Summary of frequency-related training studies

Author (year)	Participants and training history	Training performed by each group: sets x reps	Total volume controlled?	Notable performance changes (% change, ES) ↑↑ = significant change ↑ = non-significant change
Braith et al. (1989) (22)	117 untrained participants (47 males and 44 females trained; 26 were controls)	G1 (n = 44; 22 males, 22 females): 1 x 7-10RM for 10-weeks G2 (n = 47; 27 males, 25 females): 1 x 7-10RM for 18-weeks  Within each group participants trained for either 2 days per week (2D) or 3 days per week (3D) utilising the knee extension.	No	G1-2D ↑↑ MVIC Knee Ext (13.5%) G1-3D ↑↑ MVIC Knee Ext (21.2%) G2-2D ↑↑ MVIC Knee Ext (20.9%) G2-3D ↑↑ MVIC Knee Ext (28.4%)  3D improved significantly more than 2D.
Hoffman et al. (1990) (77)	61 NCAA Division IAA football players	G1 (n = 12): Full body routine, three days per week (average of 1,389.6 repetitions per week) G2 (n = 15): Split routine, four days per week (average of 1,046.4 repetitions per week) G3 (n = 23): Split routine, five days per week (average of 1,328.0 repetitions per week) G4 (n = 11): Split routine, six days per week (average of 1,466.4 repetitions per week)  For 10-weeks, periodised, intensity ranging from 10RM to 2RM. Three exercises maximum per body part, except for the G4 with four.	No	G1 ↑ 1RM SQ (5.2%, 0.24) & BP (1.8%, 0.09) G2 ↑↑ 1RM SQ (7.3%, 0.37) ↑ BP (3.5%, 0.32) G3 ↑↑ 1RM SQ (7.5%, 0.62) & BP (3.2%, 0.21) G4 ↑↑ 1RM SQ (6.5%, 0.34) ↑ BP (4.0%, 0.39)  G3 was the only group to show significant improvements in both 1RM SQ and BP.
Arazi & Asadi (2011) (7)	39 untrained males (10 as controls)	G1 (n = 10): 12 exercises, all performed one day per week G2 (n = 10): 12 exercises, spread across two days a week G3 (n = 9): 12 exercises, spread across three days a week  For eight-weeks, periodised from 12 repetitions at 60% 1RM initially to six to eight repetitions at 80% 1RM.	Yes	G1 ↑↑ 1RM LP & BP G2 ↑↑ 1RM LP & BP G3 ↑↑ 1RM LP & BP  No significant differences between groups.
Gentil et al. (2014) (54)	30 untrained males	G1 (n = 15): Once per week      G2 (n = 15): Twice per week  For 10-weeks, utilising the same nine exercises for 3 x 8-12RM each day	Yes	G1 ↑↑ LVIC Elbow Flex (6.7%, 0.34) G2 ↑↑ LVIC Elbow Flex (12.9%, 0.58)  No significant differences between groups.

Candow & Burke (2007) (26)	29 untrained participants (six males, 23 females)	G1 (n = 15; 3 males, 12 females): Two days per week, 3 x 10RM G2 (n = 14; 3 males, 11 females): Three days per week, 2 x 10RM  For six-weeks, each utilising the same nine exercises.	Yes	G1 ↑↑ 1RM SQ (29%) & BP (22%) G2 ↑↑ 1RM SQ (28%) & BP (30%)  No significant differences between groups.
McLester et al. (2000) (108)	18 recreationally trained (≥ three days weight training per week, consistently)	G1 (n = 9; 14 males, 11 females): Three sets per exercise on one day G2 (n = 9; 5 males, 4 females): One set per exercise on three days  For 12-weeks, periodised, intensity ranging from 10RM to 3RM. Utilising the same nine exercises each day.	Yes	G1 ↑ 1RM LP (22.3%, 0.54) & BP (10.6%, 0.28) G2 ↑ 1RM LP (46.1%, 0.84) & BP (27.1%, 0.55)  All upper and lower body 1RM's significantly improved when groups were combined. G2 improved 1RM LP significantly more than G1.
Schoenfeld et al. (2015) (142)	20 weight-trained males (≥ three days per week, for ≥ one year)	G1 (n = 8): 7 x 3RM                      G2 (n = 9): 3 x 10RM  For eight-weeks. A total of nine exercises were trained across three days of the week. G1 trained full body each day, while G2 trained one area of the body each training day.	Yes	G1 ↑↑ 1RM SQ (34.8%, 0.74) & BP (10.6%, 0.46) G2 ↑↑ 1RM SQ (18.9%, 0.64) & BP (8.2%, 0.41)  After adjusting for baseline values, it was found that G1 improved significantly more in 1RM BP than G2.
Häkkinen & Kallinen (1994) (62)	10 strength-trained females (≥ two years)	Two groups (each n = 5) performed two three-week blocks of training once or training twice daily. The order was reversed in each group.  Training occurred every two days. Intensity varied from 70-100% 1RM, one to three repetitions per set for 18-22 repetitions per set for the squat; while other exercises were performed (60-80% 1RM) to a total of six exercises each session (once daily) or three each session (twice daily).	Yes	Once daily ↑ MVIC Knee Ext (0.1%) Twice daily ↑↑ MVIC Knee Ext (4.8%)  Twice daily training significantly improved MVIC Knee Ext compared to once daily.
Hartman et al. (2007) (71)	10 competitive male weightlifters	G1 (n = 5): Performed all training in a single training session per day G2 (n = 5): Performed training split into two sessions per day  Four days per week, for three weeks. Four exercises were performed each training day, intensity ranging from 75-95% 1RM.	Yes	G1 ↑ MVIC Knee Ext (3.2%, 0.07), 1RM Snatch (0.6%, 0.04) and Clean and Jerk (0.3%, 0.01) G2 ↑ MVIC Knee Ext (5.1%, 0.18), 1RM Snatch (0.5%, 0.03) and Clean and Jerk (1.9%, 0.06)

BP = Bench press; BW = Bodyweight; ES = Effect size; Ext. = Extension; G = Group; LP = Leg press; LVIC = Low velocity isokinetic concentric contraction; MTP = Mid-thigh pull; MVIC = Maximal voluntary isometric contraction; RM = repetition maximum; SQ = Back squat; ↓ indicates decreased; ↑ indicates increased.

*N.B. Effect sizes and percentage changes were calculated wherever sufficient data could be obtained in manuscripts, otherwise reported values were used (if available).*

Several studies have controlled for total training volume with previously untrained participants (7, 26, 54). Arazi & Asadi (7) trained participants one, two or three days per week. Exercises were either performed on one day, or spread amongst the training days. All groups significantly increased 1RM leg press and bench press, but no differences were found between groups. Gentil et al. (54) trained the upper body with eight exercises on one day, or spread across two days per week. Both groups significantly increased peak torque with no significant differences between groups. Candow and Burke (26) performed two or three-sessions per week, with three or two sets each day, respectively. Both groups showed statistically significant improvements in squat and bench press strength, with no differences between groups. The above studies suggest that total training volume has a greater influence on strength improvements than training frequency in previously untrained individuals.

Other studies have investigated volume controlled training frequency in trained participants (108, 143). McLester et al. (108) had weight-trained participants perform one set to failure three times per week, or three sets to failure one time per week. Significant increases occurred for all upper body and lower body 1RM's tested. The only significant change between groups was in the leg press where the three-day group improved significantly more. Although not significant, the one-day group only achieved  $\approx 62\%$  of the combined 1RM improvement of the three-day group for the upper body, and  $\approx 63\%$  for the lower body combined 1RM. It should be noted that the three-day group contained more females (seven out of nine) than the one day per week group (four out of nine). The results of this study show that there may be a benefit of increased training frequency, even when volume is held constant. Schoenfeld et al. (142) split 21 exercises across three training days with weight-trained participants. The three training days were performed as a full body or split routine, meaning each body part was trained on one day or three days of the week, for a similar total weekly volume. Both 1RM bench press and back squat improved significantly, but there were no differences between groups. While these studies show mixed results, it appears that even in well trained participants training volume may have a greater effect on strength improvements than training frequency.

Several meta-analyses have also investigated the optimal weekly training frequency (121, 133). Rhea et al. (133) found that untrained individuals respond best to training each muscle group up to three days per week, while trained individuals respond better to two days per week to produce maximal gains in strength. It should be noted that the authors also stated that many of the studies employing a two day per week programme used relatively high volumes on each of the two training days, and therefore this may play a role in the results found due to the required recovery from strenuous sessions. Peterson et al. (121) found no difference between training muscle groups two or three times a week in athletes. These results suggest that training each muscle group at least two times per week is required for optimal strength gains. It should be noted that training each muscle group twice per week may result in training many days per week, depending on the approach (split or full body) utilised.

Limited research has investigated training multiple times per day, however it is well known that elite weightlifters may frequently perform two or more sessions within a single day (45, 155). These sessions are often at high intensities ( $\geq 80\%$  1RM) and multiple sessions may be performed almost every day of the week (155). This appears contradictory to the meta-analyses that have been conducted (133). However, these elite lifters show long term progression and thus appear not to be in an overtrained state (67, 68). Häkkinen and Kallinen (62) showed that, in females, distribution of daily training volume into two sessions improved maximal strength in comparison to performing the same volume in one session, for a three week training period. Hartman et al. (71) trained competitive weightlifters with either one or two sessions per day, four days per week, for three weeks. No additional benefit was found to two sessions over one. However, non-significant increases in isometric forces were slightly larger in the twice daily group (5.1% vs 3.2%). This suggests that daily training frequency may play a role in enhancing maximal strength and that separating training sessions into smaller blocks may enhance the gains in maximal strength. It should be noted that these studies were performed with small numbers of participants.

Training frequency appears to have a greater impact on maximal strength improvements when volume increases along with the number of training sessions (22, 76). The positive effect of a higher frequency is less clear when volume is controlled

(54, 142), however there may be some benefit to increased training frequency in well trained individuals (62, 108), but the data is inconclusive. It is recommended that individuals aiming to increase maximal strength train each muscle group at least twice per week (121, 133).

### **2.3.2 Adaptations to Training Frequency**

Muscular hypertrophy may be one of the major adaptations due to increased training of frequency. Hoffman et al. (77) found four days of resistance training per week significantly decreased bodyweight, while all frequencies tested (three to six days per week) significantly reduced sum of skinfolds. Thigh circumference was also significantly increased in four and five days per week groups, while chest circumference increased in three, four and five days per week groups. This suggests an effect of training frequency on muscular hypertrophy when volume is not controlled. Candow and Burke (26) showed similar improvements in lean tissue gain, using dual energy x-ray absorptiometry, when training for two-sessions (2.9%) or three-sessions (3.0%) of equal weekly volume over 10-weeks. Arazi and Asadi (7) found increased body mass and decreased body fat, based on skinfolds, in the one, two and three days per week groups. The two-day and three-day groups increased thigh circumference, while the one and three-day groups increased arm circumference. Indicating similar changes regardless of training frequency (from one to three days) when volume is held constant in untrained participants. Gentil et al. (54) demonstrated that flexed arm girth and elbow flexor muscle thickness, using B-Mode ultrasound, significantly increased whether training one or two days per week. There were no significant differences between groups, however, the two-days per week group increased by more for both values than the one-day per week group (6.6% vs. 4.7% for flexed arm girth, and 7.1% vs. 5.5% for elbow flexor muscle thickness). Schoenfeld et al. (142) found that muscle thickness (measured using A-Mode ultrasound) of the elbow flexors increased significantly in both the split and full body routines, but a larger increase was seen for the full body routine (6.5% vs 4.4%). Muscle thickness of the elbow extensors and vastus lateralis also improved in both groups, no significant differences were seen between groups. However, in both cases the full body routine tended to have larger improvements (8.0% vs. 5.0% for the elbow extensors, and 6.7% vs. 2.1% for the vastus

lateralis). These results tend to show similar improvements in hypertrophy across training frequencies of two or more days per week. It should be noted that measuring changes in lean body mass and girths may give indications of increased muscle mass but may not be as sensitive, or specific, as other methods such as ultrasound or magnetic resonance imaging (15).

A meta-analysis by Schoenfeld et al. (140) investigated the effects of training frequency on hypertrophy. They concluded that when training is volume controlled, training a muscle group twice a week promoted greater gains in hypertrophy than one day per week (ES = 0.49, vs ES = 0.30). However, it could not be determined if three days was superior to two, therefore the authors recommended that for muscle growth each muscle group should be trained at least twice per week.

Few studies have investigated the hormonal or neuromuscular effects of training frequency. Häkkinen and Kallinen (62) showed that, in females, distribution of daily training volume into two sessions produced greater increases in CSA of the quadriceps, and individual changes in EMG that correlated significantly with strength improvements. These findings indicate conditions more optimal for hypertrophy and the neuromuscular system, when training stimuli is split into smaller blocks. Hartman et al. (71) showed a similar increase in cortisol (30%) for single or twice daily training sessions. However, greater increases in neuromuscular activation (20.3% vs. 9.1%) and testosterone (10.5% vs. 6.4%) were found for a double vs single daily training, but these changes were not significant. Further research is needed to determine the hormonal and neuromuscular responses to training programmes utilising different daily training frequencies.

The hypertrophic response to increases in training frequency is similar with two or more training sessions per muscle group per week (140), a change that appears similar to the response of maximal strength (121). There appears to be potential for greater enhancements in the neuromuscular activation and endocrine responses with training volume distributed into smaller sessions (62, 71), but such changes require further investigation.

## 2.4 Periodisation

Thus far training variables have been discussed in terms of optimal numbers for improving strength. However, manipulating and providing variation in each of these variables may provide greater gains in maximal strength (185). Athletes frequently plan, or periodise, training in order to achieve maximal performance at a given time point (48).

Traditional approaches to periodisation involve high volume and low intensity at the start of a training cycle, then as a training cycle progresses volume is reduced and intensity increases (72, 159). Repetition ranges may decrease week by week, be held constant for a period of time before reducing, or progress in waves, however the general trend in traditional models is towards greater intensity and lower volume over time (167). Block periodisation differs in its focus on specific workloads for a period of weeks as a concentrated training block before the focus shifts. Blocks may focus on one fitness component or multiple compatible fitness components, with the main objective being to produce a greater training stimulus (84). The order of each block is logical in that it should prepare the athlete for the subsequent training block, it may also often follow in a similar fashion to traditional models whereby higher volume blocks occur earlier in the training cycle (13). Undulating periodisation is another popular approach and involves more frequent changes in volume and intensity of training (69). Daily undulating periodisation (DUP) involves changes in these variables on a day by day basis, while weekly undulating periodisation involves changes in these variables on a weekly basis (69, 72). DUP is characterised by a session by session training focus, typically a hypertrophic focused session, a strength focused session and a power focused session within a week (order may vary). It has been suggested that the more frequent alterations in training variables could provide greater neuromuscular stimulation and thus enhanced adaptations (185). Traditional, block and undulating approaches of periodisation in trained populations will be the focus of this section. Table 2.4 shows a summary of periodisation training studies discussed.

**Table 2.4:** Summary of periodisation training studies

Author (year)	Participants and training history	Training performed by each group: sets x reps	Total volume controlled?	Notable performance changes (% change, ES) ↑↑ = significant change ↑ = non-significant change
Willoughby (1993) (178)	92 weight-trained males (1RM BP ≥ 1.2 x BW; 1RM SQ ≥ 1.5 x BW; 23 as controls)	G1 (n = 23): 5 x 10RM (78.9% 1RM) G2 (n = 23): 6 x 8RM (83.3% 1RM) G3 (n = 23): Four week periodised blocks, intensities from 10RM to 4RM  Three days per week of SQ & BP for sixteen weeks.	Yes W1-8 No W9-16	G1 ↑↑ 1RM SQ & BP G2 ↑↑ 1RM SQ & BP G3 ↑↑ 1RM SQ & BP  G3 was significantly higher than all groups after eight weeks in the BP, and in both exercises by week 16.
Stone et al. (2000) (153)	21 weight-trained males (SQ ≥ 110 kg and ≥ 1.3 x BW)	G1 (n = 5): Major 5 x 6RM, assistance 3 x 8RM for 12-weeks. G2 (n = 9): Four week periodised blocks, intensities from 10RM to 3RM G3 (n = 7): Similar to G2, but higher volume weeks at weeks one and nine  Three days per week, for 12-weeks. Exercises were the same on two days, while on the other day different exercises were trained.	Yes G1 & G2 No G3	G1 ↑ 1RM SQ (9.9%, 0.54) G2 ↑↑ 1RM SQ (14.9%, 1.54) G3 ↑↑ 1RM SQ (15.4%, 1.13)
Baker et al. (1994) (10)	22 weight-trained males (1RM SQ and BP > BW)	G1 (n = 9): Major 5 x 6RM, assistance 3 x 8RM for 12 weeks G2 (n = 8): Four week linear periodised blocks, intensities from 10RM to 3RM G3 (n = 5): Alternative higher and lower repetition ranges every fortnight, with a general trend towards lower repetitions  Three days per week, for 12-weeks. Utilised a full body training programme with five to six exercises a day.	Yes	G1 ↑↑ 1RM SQ (24.9%, 1.37) & BP (12.2%, 0.86) G2 ↑↑ 1RM SQ (25.3%, 1.01) & BP (11.4%, 0.75) G3 ↑↑ 1RM SQ (25.2%, 1.01) & BP (16.0%, 1.13)  No significant differences between groups.
Hoffman et al. (2009) (78)	51 NCAA Division III football players	G1 (n = 17): Consistent three to four sets of 6-8RM for traditional exercises and 3-4RM for Olympic lifting movements. G2 (n = 17): A hypertrophy phase (four weeks), a strength phase (six weeks) and a power phase (four weeks). G3 (n = 17): Alternated each training session between a power workout and a hypertrophy workout.  Four days per week, for 15-weeks. Exercises were identical in each group.	No	G1 ↑↑ 1RM SQ (20.4%, 1.58) & BP (8.7%, 1.00) G2 ↑↑ 1RM SQ (20.7%, 1.43) & BP (7.8%, 0.47) G3 ↑↑ 1RM SQ (11.1%, 0.75) & BP (8.3%, 0.40)  No significant differences between groups.

Monteiro et al. (2009) (110)	27 weight-trained males (≥ four days per week, for ≥ two years)	G1 (n = 9): Consistent loading 3 x 8-10RM G2 (n = 9): Four week linear periodised blocks, intensities from 15RM to 4RM G3 (n = 9): Alternated each training day between higher, medium and lower repetition ranges. The intensities were in the same range as G2.  Four days per week, two days repeated each week (split routine). Except the final microcycle were three smaller sessions occurred per week.	Yes	G1 ↑ 1RM LP (1.10) & BP (1.00) G2 ↑↑ LP (1.10) ↑ BP (0.60) G3 ↑↑ 1RM LP (4.60) & BP (2.90)  G3 improved 1RM LP & BP significantly more than G1 or G2. No percentage change data available.
Bartolomei et al. (2014) (13)	24 weight-trained males (≥ three days per week, for ≥ three years of training)	G1 (n = 12): Three five week mesocycles; week one 5 x 8-10 (65-75% 1RM), week two 5 x 5-6 (75-85% 1RM), week three 5 x 3-4 (85-95% 1RM), week four power focus at 50-60% 1RM, week five recovery with two sessions only. G2 (n = 12): Three five week blocks; block one, accumulation 6-10RM (65-75% 1RM), then block two, strength 1-6RM (80-95% 1RM), finally block three, power at 50-65% 1RM.  Four days per week, split routine. Both groups utilised the same exercises.	Yes	G1 ↑ MVIC SQ (7.8%, 0.22) & 1RM BP (2.0%, 0.08) G2 ↑ MVIC SQ (4.8%, 0.20) & 1RM BP (7.6%, 0.40)  There were no significant differences between groups. However, magnitude-based analysis demonstrated a “possibly positive” result in favour of G2 over G1 for 1RM BP.
Miranda et al. (2011) (109)	20 weight-trained males (≥ three days per week, for ≥ two years)	G1 (n = 10): Four week linear periodised blocks, intensities from 10RM to 4RM G2 (n = 10): Daily variations; a higher (8-10RM), medium (6-8RM) and lower (4-6RM) repetition day were alternated between.  Four days per week, as a two day split, for 12-weeks. Exercises were consistent in each group. G1 and G2 differed only in the first exercise each day (LP and BP), assistance always 3 x 6-8RM.	Yes	G1 ↑↑ 1RM LP (5.9%, 0.74) & BP (15.1%, 0.75) G2 ↑↑ 1RM LP (18.2%, 1.52) & BP (16.3%, 0.95)  No significant differences between groups. G2 greater magnitudes of change than G1.
Painter et al. (2012) (119)	26 track athletes (19 males, seven females)	G1 (n = 14): Three blocks, first strength/endurance, second strength and the final block of power focus. G2 (n = 12): Daily variations each week, day one strength/endurance, day two strength and day three power.  Three days per week, for 10-weeks. Both groups utilised the same exercises and similar repetition ranges for each training goal.	No	G1 ↑ 1RM SQ (3.9%, 0.12) & MTP (15.1%, 0.41) G2 ↑ 1RM SQ (1.5%, 0.05) ↑↑ MTP (14.7%, 0.53)  1RM SQ improved over time when groups were combined. No significant differences were found between groups.

Colquhoun et al. (2017) (33)	25 weight-trained males ( $\geq$ six months training, squat 1.25 x BW, BP 1.0 x BW and DL 1.5 x BW)	G1 (n = 14): Daily variations; day one hypertrophy, day two power, and day three strength training focus. G2 (n = 11): Completed the same three sessions as G1 but could select the order of the training days.  For nine weeks. Utilising the same exercises within each training group.	Yes	G1 $\uparrow\uparrow$ SQ (12.2%, 0.64), BP (7.5%, 0.42), DL (7.8%, 0.50) and Total (9.2%, 0.58) G2 $\uparrow\uparrow$ SQ (11.8%, 0.46), BP (6.8%, 0.33), DL (8.9%, 0.38) and Total (9.3%, 0.42)  No significant differences were found between groups
Zourdos et al. (2016) (185)	18 male powerlifters (1RM SQ & DL $\geq$ 2 x BW; 1RM BP $\geq$ 1.25 x BW)	G1 (n = ): Daily variations, order: hypertrophy, strength then power G2 (n = ): Daily variations, order: hypertrophy, power then strength  Three days per week, for six-weeks. All exercises were the same between groups. Hypertrophy progressed biweekly from five to three sets of eight (weight initially 75% then autoregulated); strength was three AMRAP sets progressing biweekly from 85 to 95% 1RM; power was singles progressing biweekly from five to three sets from 80 to 90% of 1RM.	No	G1 $\uparrow\uparrow$ 1RM SQ (7.9%, 0.70), DL (10.8%, 0.78) and Total (6.7%, 0.53) $\uparrow$ 1RM BP (2.7%, 0.17) G2 $\uparrow\uparrow$ 1RM SQ (10.5%, 0.79), BP (8.1%, 0.58), DL (10.6%, 0.77) and Total (8.7%, 0.70)  G2 improved 1RM BP significantly more than G1. Combined total volume was higher in G2 than G1.
AMRAP = As many repetitions as possible; BP = Bench press; BW = Bodyweight; DL = Deadlift; ES = Effect size; G = Group; LP = Leg press; MTP = Isometric mid-thigh pull; MVIC = Maximal voluntary isometric contraction; RM = repetition maximum; SQ = Back squat; Total = Combined total of 1RM SQ, BP & DL; $\downarrow$ indicates decreased; $\uparrow$ indicates increased, $\leftrightarrow$ indicates unchanged.				

*N.B. Effect sizes and percentage changes were calculated wherever sufficient data could be obtained in manuscripts, otherwise reported values were used (if available).*

### 2.4.1 The Effects of Periodised Training on Maximal Strength

Studies have demonstrated the effectiveness of a periodised approach using forms of traditional periodisation in comparison to constant loading (153, 178). Willoughby (178) showed the superiority of a periodised approach over 16 weeks using weight-trained participants, with partially equated workload. Both constant loaded groups achieved similar gains in 1RM strength of the bench press and back squat, while the periodised group showed enhanced strength in comparison to each of these groups. Stone et al. (153) observed significant improvements in squat 1RM for periodised training groups, but not the non-periodised group. Although the two periodised groups began the study with a lower starting strength (not significantly), the authors stated that five strongest athletes in each group showed the same trends. These studies display the effectiveness of a periodised approach to training.

Different forms of periodisation have also been compared. Baker et al. (10) performed a comparison of non-periodised training with both traditional and a form of bi-weekly, undulating periodisation in weight-trained individuals. Training was equalised in terms of volume and intensity. The 1RM bench press and squat improved for all groups with no significant differences between groups. Hoffman et al. (78) trained National Collegiate Athletic Association (NCAA) Division III football players with non-periodised, linear periodised (in blocks) or non-linear periodised (daily variations) training. All groups significantly improved 1RM squat and bench press, with the greatest gains in the initial half of the 15-week training period. No differences were found between groups. These findings contrast with the previous findings (153, 178). However, Monteiro et al. (110) implemented a similar study to Hoffman et al. (78), comparing no periodisation (constant loading), linear-periodisation (utilising blocks) and non-linear periodisation (daily variations). The non-linear group significantly increased 1RM for both the leg press and bench press. The linear group also significantly improved 1RM leg press while non-periodised training did not significantly improve strength. Block periodisation was compared to traditional weekly changes by Bartolomei et al. (13) who found no significant differences between groups. Their results also exhibited no significant increases in strength measures (1RM bench press approached significance,  $P = 0.058$ ). Although not significant, small ES's were displayed for increases in isometric

squat for both linear and block models (0.22 and 0.20, respectively), while only block showed a small ES for 1RM bench press (ES = 0.40). These results are inconclusive in demonstrating any specific periodisation strategy as superior.

DUP has also been a focus of investigation. Miranda et al. (109) compared linear periodisation with DUP in previously weight-trained participants. Both groups showed significant improvements in 1RM by the end of the study, with no significant differences between groups. However, although not significant the DUP group displayed improvements of a larger magnitude for leg press (18.2% vs. 5.9%). While Painter et al. (119) showed more efficient strength gains (i.e. less repetitions performed for similar improvements) from block periodisation compared to DUP, with no differences group differences in strength improvements. Colquhoun et al. (33) found a self-selected order of three DUP training sessions to have equal efficacy to a set arrangement of Hypertrophy-Power-Strength within each training week, with both groups significantly improving maximal strength across all powerlifting movements. Zourdos et al. (185) compared different configurations of DUP over six weeks in trained powerlifters. A classical DUP order of hypertrophy, then strength, then power was compared to an alternative order of hypertrophy, then power, then strength; aiming to provide greater rest between the high-volume hypertrophy day and the high-load strength day. Significantly greater training volume could be performed in the alternative configuration for squat and bench press training, as well as significantly greater increases in 1RM bench press strength. The powerlifting total also favoured the alternative configuration. These results show that DUP can be an effective strategy for improving strength (33, 109) and the alternative configuration as potentially superior to the classical arrangement for strength (185). These results suggest that DUP may provide an effective training stimulus in trained participants.

Several meta-analyses have been performed on the effects of periodisation on maximal strength (69, 130, 177). Rhea and Alderman (130) concluded that periodised training was significantly more effective at increasing strength and power measures, with ES = 0.84 (when not controlling for volume and intensity). Effectiveness of periodised training was shown in untrained (ES = 1.59), recreationally trained (ES = 0.78), as well as athletic populations (ES = 0.84). This effect was lower, but still

significantly higher than non-periodised training, when controlled for volume and intensity,  $ES = 0.25$ . These findings indicate that both the ability to train with greater volume and intensity, as well as the manipulation of these variables helps to enhance strength. Harries et al. (69) performed a meta-analysis specifically comparing traditional (linear) and undulating periodisation models and concluded that there were no differences between the types of periodisation for upper or lower body strength. In a recent meta-analysis, Williams et al. (177) concluded that a periodised approach to training is superior to non-periodised training, with an overall  $ES = 0.43$ , the effect was still significant (but smaller) when outliers were removed ( $ES = 0.23$ ). They also concluded that, in contrast to Harries et al. (69), undulating periodisation has a more favourable effect on 1RM than traditional periodisation. These meta-analyses show that periodised approaches are more effective than non-periodised approaches, and that undulating periodisation may provide additional benefits to traditional periodisation models.

Periodised training generally provides greater increases in strength than non-periodised training in trained participants (153, 178). The optimal style of periodisation in strength-trained populations requires more research, however, it appears that DUP may provide some benefits in well trained populations (185). It is recommended that trained participants undertake periodised strength training in order to enhance maximal strength.

#### **2.4.2 Adaptations to Periodised Training that Enhance Strength**

Periodisation is a planned manipulation of training variables over time and thus, the adaptations specific to periodisation are the same adaptations discussed in earlier sections of this review. However, through manipulation of these training variables, progressive adaptations may be possible that allow athletes to achieve maximal performance at a date in the future (167).

Traditional periodisation approaches to strength training are initiated with a period of hypertrophy (or muscular endurance) focus. This style of training achieves a higher volume of training than specific maximal strength training and thus enhances the

ability to gain muscular hypertrophy through accumulated volume that may not be attained with a sole maximal strength focus in training (138). High volume periods allow an athlete to enhance their muscle mass and thus increase the quantity of contractile units and enhance work capacity (48). Such an adaptation will benefit an athlete at later stages of training; as they move towards higher intensity training, adaptations to the neuromuscular system will mean better utilisation of this additional muscle mass and thus achieve enhanced strength. One of the basic premises of this design is initial training primarily stresses the muscle (high volume), while later training primarily stresses the nervous system (high intensity and more highly skill focused) (152). Baker et al. (10) found that around 50% of strength improvements could be correlated with increases in LBM in each of their three training groups. Bazyler et al. (14) demonstrated significant improvements in vastus lateralis muscle thickness following a block periodised training model. The addition of contractile units may be blunted if training volume was consistently lower (i.e. training solely with a low number repetitions and large load). In fact a trend was seen towards unchanged LBM when volume was reduced in the traditional periodisation regime in Baker et al. (10). Monteiro et al. (110) also found no increase in LBM while still observing enhanced strength in trained individuals, attributing the changes seen to neural factors (not measured), potentially due to the participants being more trained. Another advantage of periodisation is as volume is decreased, peripheral fatigue will be reduced as the overall stress on the muscular system is less. Zourdos et al. (185) found testosterone decreased during training but was restored to pre-training levels at post-testing after the final weeks of periodised training, which included a taper week. Such management of fatigue (and avoiding overtraining – see section 2.5.2) is frequently cited as a reason for the planned training undertaken during periodisation (177). Thus, neuromuscular adaptations due to variations in resistance training volume and intensities, as well as a decreased risk of overtraining, tend to be the primary adaptations, or goals, of periodised training.

Different styles of periodisation manipulate these variables in specific ways, with each having potential strengths and weaknesses. Undulating periodisation advocates have criticised traditional periodisation due to its ever increasing intensity of training, a risk for neural fatigue (10). However, wave loading is frequently used within a traditional

periodised plan, and the use of unloading (or recovery) periods is also frequent (122). Hence, through appropriate planning such a risk can be avoided. Advocates of the traditional periodisation have criticised the undulating approach due to its consistently higher volume loads and the risk for peripheral fatigue (61). Yet with DUP, risks of fatigue can be minimised through appropriate progressions (i.e. reductions in total weekly volume over time) and use of unloading periods (185). Thus, a well-planned, periodised training regime can avoid potential risks of overtraining, and allow an athlete to achieve long term performance advantages.

## **2.5 Other Training Considerations**

An overview has been given of some of the major considerations in designing a training programme to enhance maximal strength and the adaptations that occur. This section briefly covers areas that must also be considered for a programme to be effective. The first two areas are related to previous literature regarding fatigue. The first discusses fatigue during a workout in terms of optimising outcomes of training through rest periods between sets. The second looks at how overtraining may influence maximal strength. Finally, the opposite, detraining, will be briefly touched on.

### **2.5.1 Rest Periods between Sets**

Fatigue has been defined as the inability to maintain performance at a set intensity due to physical or mental stressors (44). In the case of resistance training this may mean the inability to perform a set number of repetitions at a given, or expected, load. This may occur intra-workout (e.g. insufficient rest period between sets) or could occur inter-workout (e.g. insufficient rest between training sessions) (172). Therefore, appropriate rest periods are required between exercise sets, as well as between training sessions, if an athlete is to be exposed to an effective training stimulus.

Rest periods between sets in training are required for an athlete to be able to lift a given load. For example, Larson and Potteiger (96) found participants' repetitions achieved when lifting to failure decreased from  $\approx 16$  in the first set to  $\approx 7$  in the fourth set, regardless of between 100-180 second of rest. Weiss (172) stated that if an

individual is performing an activity that primarily requires strength then they should take sufficient rests to allow primary use of the adenosine triphosphate system. Such rests may potentially be even greater than the recommended three to five minutes (61). This is to minimise fatigue which may hinder the ability to produce large forces, thus inhibiting the optimal training stimulus (172).

If multiple sets are required to achieve greater targeted training volumes, long rests will extend the total training duration and may be impractical. Kraemer et al. (91) showed that shorter rest periods appear to promote greater human growth hormone responses, independent of total work performed. Tan (159) also stated that higher volume, moderate intensity training with shorter rests may stimulate greater testosterone responses. However, a recent study by Schoenfeld et al. (141) found interesting results when intensity and volume were similar (three sets at 8-12RM). Longer rest periods (three minutes) showed a significantly greater increase in strength of both 1RM squat and bench press than shorter rest periods (one minute; squat 15.2% compared to 7.6%, and bench press 12.7% compared to 4.1%). Longer rest periods also showed a greater impact on hypertrophic outcomes. This study suggests that longer rest periods may be more effective for maximal strength gains and may also enhance CSA to a greater degree.

Therefore, to enhance maximal strength, intra-workout rest periods should allow for sufficient recovery between sets. Such rests will ensure that an athlete is able to lift a load great enough to elicit an effective training stimulus for multiple sets (172). This will ensure recruitment of type II motor units can continue to occur, as well as ensure optimal technique can continue to be employed (to enhance efficiency of movement).

### **2.5.2 Effects of Overreaching and Overtraining on Strength**

In section 2.3 optimal number of training days per week was discussed, along with effective inter-workout rest periods. However, planned periods of overreaching may lead to greater supercompensation with a planned unloading (or taper) period, and thus enhance strength to a greater degree (8).

Overreaching and overtraining are conditions of training induced fatigue which result in performance decrements, but differ in the duration of required recovery. Specifically, overreaching can be recovered from in the short term (days), whereas overtraining will take much longer (weeks or months) (50). These conditions can occur through increasing the number of sessions performed per week, or by increasing volume or intensity of each training session. If overreaching is to be implemented it should be well planned with sufficient recovery periods, to avoid the risk of overtraining (50).

The ability to recover from planned overreaching has been shown in the literature (67, 156). Storey et al. (156) had seven international weightlifters (four male, three female) increase training frequency from an initial week of six sessions, to 10 sessions per week for two weeks (173% of initial training volume, based on repetitions), before a reduction to nine sessions per week (141% of initial training volume) in the fourth week. Mean training intensity also increased, to 112% and 115% of initial week in weeks two and three respectively, before reducing to 104% in week four. Interestingly, their results showed no change in clean and jerk performance over the two weeks of intensified training, while snatch performance decreased during intensified training, but was restored following the reduced week. Similarly, Häkkinen et al. (67) performed two weeks of higher volume training followed by two weeks of normal training, before reducing training for two weeks. During the high volume training testosterone and testosterone to cortisol ratio decreased; while during the reduced training period cortisol levels decreased, and the testosterone to cortisol ratio showed slight, non-significant, increases. Weightlifting performance improved after the full training period, indicating the importance of planned reductions in training load if overreaching is employed. Demonstrating the potential effectiveness of well-planned overreaching with sufficient recovery. However, it is imperative that an athlete is well monitored during planned periods of overreaching, as continued exposure to high training volumes or intensities could move an athlete from a state of overreaching to a state of overtraining (50).

### **2.5.3 Avoiding Detraining**

In Chapter Three the effects of training cessation are discussed. Therefore, the focus of this section is to briefly cover how negative effects of detraining (particularly decreased maximal strength) can be avoided in the context of the previous literature. It is well known that training effects are reversible (61), but maintenance may be possible with limited exposure to appropriate stimuli (59, 161).

If previously acquired strength levels are to be maintained, not enhanced, a lower training stimulus may suffice. Graves et al. (59) reduced training frequency of 50 previously untrained participants (26 males, 24 females) from two or three days per week, to two, one or complete cessation. This reduction occurred for 12-weeks, following an earlier 10 or 18-week training period (one set per training session at 7-10RM on leg extension). Participants who reduced their training to one or two days per week showed no decrements in strength, while those who ceased training lost 68% of their strength gains from prior training. Tavares et al. (161) found similar results. After training 33 previously untrained participants for eight weeks (three days per week, for three to four sets at 6-12RM, on the half squat and knee extension), training frequency was reduced for a further eight weeks. Groups that still performed one or two days of resistance training per week (total volume was similar) maintained their enhanced strength and quadriceps CSA, while those who ceased training decreased 1RM half-squat strength by 22.6% and quadriceps CSA by 5.4%. These results show that continuing to train for at least one day a week may be sufficient to maintain a previous level of strength and hypertrophy, at least in individuals with limited training experience.

### **2.5.4 Training Mode**

Resistance training can be performed using various modalities. The focus of this chapter has been traditional resistance training (i.e. the use of barbells, dumbbells and machine weights). However, such implements can be used to train muscle groups (or joint actions) in isolation or in groups. Typically, exercises requiring multiple muscle actions and movements across multiple joints are termed compound exercises, while

isolation exercises are the term used for exercises which involve one muscle (or muscle group) acting at a single joint (55). These movements provide differing training stimuli and thus it is important to determine which may be most effective for enhancing maximal strength.

The superiority of compound exercises has been shown in several domains (55, 61, 92). Compound exercises involving large muscle mass (e.g. deadlift, squat, Olympic weightlifting etc.) appear to have a greater effect on the testosterone response than isolation exercises that involve only small amounts of muscle mass (e.g. leg extensions, bicep curls etc.) (92). Compound exercises, particularly free weight such as squats and power cleans, closely resemble sport specific movements and so may have greater transfer to these tasks (61). Adding isolation exercises to a 10-week programme already containing compound exercises produced no additional improvements in maximal strength (peak torque of the elbow flexors) or muscle size (elbow flexor muscle thickness) (55). Furthermore, a greater loading can be achieved with the use of compound exercises in comparison to isolation exercises (61). Therefore, the use of compound exercises, that are task or sport specific, are recommended over isolation exercises to enhance strength.

### 2.5.5 Alternative Approaches to Training Prescription

Through years of observations in athletes, some strength coaches have developed their own guidelines for training prescription that have proven to be effective at enhancing maximal strength (123). Prilepin's table (see Table 2.5) is a commonly utilised approach.

**Table 2.5:** Prilepin's table

<b>Prilepin's Table</b>			
<b>%</b>	<b>Reps/Set</b>	<b>Range</b>	<b>Optimal</b>
<70	3-6	18-30	24
70-79	3-6	12-24	18
80-89	2-4	10-20	15
90+	1-2	4-10	7

Based upon selected training intensities, the chart prescribes repetitions per set, and total repetitions that should be performed for an exercise within a training session. At the higher intensities (>80% 1RM) this model of training prescription fits within the recommendations shown to be effective for enhancing maximal strength. A possible advantage of utilising this model is that athletes are not often reaching muscular failure, and thus may reduce associated risks of overtraining or injury (159). Less frequent exposure to maximal efforts has also been utilised by other strength coaches, such as perception based prescriptions (166). Therefore, such an approach could be considered useful in improving maximal strength, when applied within the research based guidelines.

## **2.6 Application to the Thesis**

Achieving peak strength relies not just on the final period of training (i.e. the tapering strategy employed) but also the training leading up to the taper (111). Reviewing the previous literature on strength training has allowed for a better understanding of the optimal methods of strength training which has assisted in designing the training methodology to be used in the training studies, Chapter Five and Chapter Six.

This literature review has shown that to enhance maximal strength there is a requirement for sufficient training volume to enhance CSA as well as sufficient intensity to enhance the neuromuscular adaptations. Athletes who have strength-trained for greater than one year generally require exposure to high training intensities ( $\geq 80\%$  1RM), for multiple sets (two or more), at least two times per major muscle group per week. Training should also have some logical variation using principles of periodisation to achieve optimal hypertrophic and neuromuscular adaptations, with a focus on free-weight compound exercises which target the major muscle groups. Each of these specific aspects has been incorporated within the training programmes utilised in this thesis to ensure an appropriate strength training stimulus is applied.

## CHAPTER THREE

### LITERATURE REVIEW TWO: EFFECTS AND MECHANISMS OF TAPERING IN MAXIMIZING MUSCULAR STRENGTH

This chapter consists of the final peer reviewed manuscript version of the following article published in the *Strength & Conditioning Journal*:

Pritchard H, Keogh J, Barnes M, and McGuigan M. Effects and mechanisms of tapering in maximizing muscular strength. *Strength & Conditioning Journal* 37(2): 72-83, 2015.

#### **Preface**

The previous chapter reviewed the literature regarding manipulation of strength training variables to enhance maximal strength. The focus of this chapter examines the literature surrounding tapering for maximal strength. That is, how the training programme should be modified prior to an important event to achieve maximal strength at a specific point in time. This chapter provides recommendations that can be utilised by athletes, and reveals areas requiring further investigation that were explored in the experimental chapters.

#### **3.1 Introduction**

Maximal muscular strength is defined as the maximal force a muscle, or group of muscles, can produce (61, 103). Improvements in maximal strength are of utmost importance for performance in strength-based sports such as powerlifting and strongman, where the ability to produce maximal force is a primary goal (53, 103, 182). Improvements in strength, specific to sporting movements have also been shown to enhance the performance of other athletes, even in sports which are primarily aerobically based (9, 75, 154). Athletes target certain competitions as major events where the aim is to perform at their peak, which is achieved through a taper (127). Tapering is a reduction in training load to recover from the fatigue of training, and it is performed before important competitions to allow optimal performance at specific

events (21, 97, 111). It is important, therefore, that athletes and coaches know how to maximize strength for key events by tapering correctly. Many studies and reviews have been written on tapering, however there is still limited research available specifically related to maximal strength, with the majority regarding endurance performance (21, 73, 79, 97, 179) and some maximal power (23, 40).

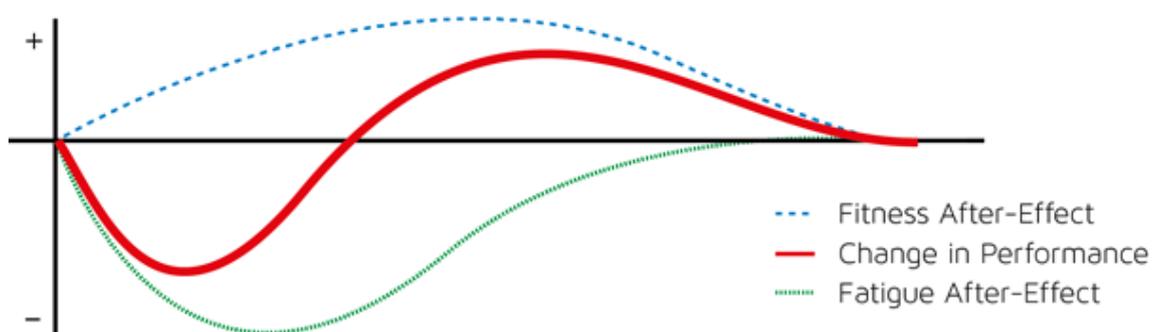
The aim of this review is to bring together what is currently known about tapering for maximal strength, to demonstrate the methods of tapering currently used in research, how these methods affect maximal strength, and the mechanisms contributing to the adaptations in maximal strength through tapering. Many coaches are uncertain of the taper phase of training, with trial and error often relied upon rather scientifically proven strategies (97). This information will be of use to coaches and practitioners to optimize athletes' performances in strength-based sports or sports where strength may help improve an athlete's performance, reducing the need for extensive trial and error. Appropriate publications were found by searching through the EBSCO Host and Google Scholar databases. Key words used in searches included the following: tapering, peaking, detraining, muscular strength, maximal strength, performance, muscle fibre types, cross-sectional area, and various combinations of these words. Effect sizes (ES) were calculated (where possible) to determine the magnitude of changes observed within studies (47). Hopkins scale for determining the magnitude of ES was used when describing these changes (81); there are: trivial 0-0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large >2.0.

### **3.2 Tapering**

Optimal performance in competition is vital; months or years of training culminate at 1 point, with the outcome determining the success or failure of ones efforts. Tapering is the final step in a training program, implemented in the last few weeks before competition and has the potential to make or break a program. Mujika and Padilla (112) defined tapering as "a progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance". This definition illustrates the

major role tapering plays to reduce stress, or fatigue, while improving fitness in order to achieve optimal performance.

The fitness-fatigue model (28), as illustrated in Figure 3.1, is a representation of the mechanism of how the taper is thought to improve performance. This model proposes that after a training session there are 2 resulting after-effects – 1 positive, fitness, and 1 negative, fatigue. Fitness after-effects may be changes, such as improved neuromuscular efficiency and hypertrophy, whereas fatigue after-effects may be changes, such as muscle damage, accumulation of metabolic waste products or disruption to hormonal balance, for example. Performance within this model can be considered the sum of the positive after-effects of fitness with sum of the negative after-effects of fatigue removed. Fatigue after-effects are usually of a greater magnitude but shorter duration than fitness after-effects which tend to have a smaller magnitude but a greater duration (28). As fatigue dissipates, performance increases can be realized, as the positive performance contributions of the fitness after-effects are not overshadowed by the negative performance contributions from the fatigue after-effects. Too much rest, however, could be detrimental, as the fitness after-effects may be reduced resulting in detraining (112). The balancing act during a taper is to ensure fatigue is minimized while fitness is maximized (97).



**Figure 3.1:** The Fitness-Fatigue model

### **3.2.1 Effects of Tapering on Maximal Strength**

Tapering can be performed in several different ways, with 4 main types being described and applied previously (113). These are step taper, linear taper, exponential

taper (slow decay) and exponential taper (fast decay). The step taper is a nonprogressive drop in training load that occurs at once and remains unchanged at a reduced level. The linear taper is a progressive reduction in training load that occurs in a linear fashion. An exponential taper is progressive and can occur with a fast or slow time constant of decay, with the training load remaining higher during the slow decay taper (113). So far, no studies have compared the effects of different styles of tapering on the expression of maximal strength, as various styles of tapering have been used across studies to date. Table 3.1 shows a summary of the studies on tapering.

Häkkinen et al. (63) performed one of the earliest studies looking at the effects of a 1-week step taper on maximal strength. Ten strength trained athletes performed 2 weeks of regular training followed by 1 week of reduced training, where volume was reduced by  $\approx 50\%$  with no changes in intensity. When split into 2 groups it was seen that the 5 stronger, Finnish national powerlifting competitors showed a statistically significant increase (by 8.3%) in leg extensor peak force during a maximal voluntary isometric contraction (MVIC) after the taper with a moderate ES of 0.61, whereas the weaker athletes showed a slight decrease (-3.6%; ES, -0.28). This study showed that well-trained strength athletes can improve their isometric strength with a step taper of only 1 week's duration.

**Table 3.1:** Effects of tapering on muscular strength

Study: Author	Subjects	Training history	Performance tests for maximal strength	Training duration before taper (d)	Taper duration (d)	Type of taper	Change in loading	Change in performance versus pre-taper value (% change, effect size) ↑ ↑ = statistically significant change ↑ = non-statistically significant change
Chtourou et al. (31)	n = 21 men	Recreationally active	MVIC of knee extension	84	14	One step taper	↑ intensity ↓ volume	↑ MVIC of knee ext. (data not available)
Coutts et al. (36)	n = 7 men	State level rugby league players	3RM BP and SQ, LVIC of knee extension & flexion	42	7	One step taper	↓ intensity ↓ volume	↑ 3RM BP (5.2%, 0.32) ↑ 3RM SQ (7.2%, 0.53) ↑↑ LVIC knee extension (45.6%, 3.85) ↑↑ LVIC knee flexion (15.6%, 0.90)
Gibala et al. (56)	n = 8 men	≥ 1-yr resistance training	LVIC and MVIC of elbow flexion	21	10	Progressive (linear)	↔ intensity ↓ volume	↑ LVIC of elbow flexion (2.8%, 0.11) ↑↑ MVIC elbow flexion (6.8%, 0.35)
Hakkinen et al. (63)	n = 10 men	5 (group A) national champions or medallists & 5 (group B) strength trained (5-10 yrs.) non-competitive	MVIC of leg extension	14	7	One step taper	↔ intensity ↓ volume	<i>Group A:</i> ↑↑ MVIC of leg extension (8.3%, 0.61) <i>Group B:</i> ↓ MVIC of leg extension (-3.6%, 0.28)
Izquierdo et al. (85)	n = 11 men	National level Basque ball players	1RM BP and SQ	112	28	Progressive	↑ intensity ↓ volume	↑↑ 1RM BP (2%) ↑↑ 1RM SQ (3%)
Zaras et al. (184)	n = 13 (7 men, 6 women)	Throwing training and competition 4.6 (SD±1.5) yrs.	MVIC LP and 1RM LP	84 or 105	14	One step taper	<i>Light Load Taper:</i> ↓ intensity (to 30% 1RM) ↓ volume <i>Heavy Load Taper:</i> ↓ intensity (to 85% 1RM) ↓ volume	<i>Light Load Taper:</i> ↑ MVIC LP (2.7%, 1.00) ↓ 1RM LP (-2.8%, 0.12) <i>Heavy Load Taper:</i> ↑ MVIC LP (14.5%, 3.00) ↑ 1RM LP (4.6%, 0.15)

ES calculated using SD of the initial value before taper.

BP = bench press; intensity = percentage of 1RM used in training; LP = leg press; LVIC = low-velocity isokinetic concentric contraction; MVIC = maximal voluntary isometric contraction; RM = repetition maximum; SQ = back squat; volume = training volume, that is sets X reps; for changes in training volume and intensity, ↔ indicates unchanged; ↓ indicates decreased; ↑ indicates increased.

Coutts et al. (36) also investigated a 1-week step taper in 7 well-trained athletes (state-level rugby league players) after 6 weeks of periodized training (to induce overreaching). This study involved reductions in both volume ( $\approx 30\text{-}40\%$ ) and intensity ( $\approx 35\%$ ), as well as training of other fitness components. Statistically significant increases were seen in maximal low velocity isokinetic torque for the knee extensors (45.6%) and flexors (15.6%) compared to the pretaper values, with very large (3.85) and moderate (0.90) ES, respectively. However, compared with pretraining there were no statistically significant improvements, with only the knee extensors showing a higher value (7.6%; ES, 0.34), whereas knee flexor strength decreased (-10.6%; ES, -0.36). Also not statistically significant, were the small increases in 3 repetition maximum (RM) on the bench press (5.2%; ES, 0.32) and squat (7.2%; ES, 0.53) compared with pretaper values. When compared with the pretraining values, no change was seen in bench press performance and the squat showed only trivial, non-statistically significant improvements (1.6%; ES, 0.11). These results suggest that after 6 weeks of overreaching (intensified, or harder than usual training) 1 week of tapering allows for improvements in strength; however, this may not be a long-enough taper to fully overcome the effects of accumulated fatigue.

Longer duration step tapers have also been investigated. Zaras et al. (184) had 13 well trained competitive throwers (7 males, 6 females) perform 2-week tapers, both a light load and a heavy-load taper, following 12 or 15 weeks of training. All participants performed both tapers and the training length before the taper was assigned in a counterbalanced fashion. Training involved resistance training, throws and plyometric training. Light-load tapering (LT) used 30% of 1RM, whereas the heavy-load tapering (HT) used 85% of 1-RM. During both tapers maximal speed of movement was emphasized. Non-statistically significant improvements were made in peak force during MVIC on a leg press in both groups, with greater increases after HT (14.5%; ES, 3.00) than LT (2.7%; ES, 1.00). 1RM leg press showed non-statistically significant improvements in the HT (4.6%; ES, 0.15), whereas non-statistically significant decreases occurred with LT (-2.8%; ES, -0.12). These results suggest that greater improvements in strength are made when volume is dropped but intensity is kept high during a taper.

Chtourou et al. (31) also performed a 2-week step taper, with recreationally active participants after 12 weeks of training. Participants were placed in morning ( $n = 10$ ) and evening ( $n = 11$ ) training groups and testing occurred at both time points. This study was focused on whether the time of day for training influenced the response to the taper if testing occurred at a different time of day. Tapering resulted in a weekly drop in training volume of  $\approx 50\%$ , with increased intensity (from 10RM to 8RM). After the taper, participants showed statistically significant improvements in performance at both testing times (morning and evening) regardless of training time of day when compared to pretraining variables. Improvements occurred after the taper but were non-statistically significant compared with pretaper results. However, no information was given on the magnitude of improvements. This study also shows that a 2-week taper is able to improve performance when volume is reduced and intensity kept high.

Reviews on tapering for endurance training indicate that progressive tapers may be most effective for performance improvements (21, 113). Currently, there have only been 2 studies investigating the effects of a progressive taper on maximal strength, with both showing promising results. Gibala et al. (56) performed a 10-day progressive (linear) taper which followed after 3 weeks of training by 8 resistance-trained ( $>1$  year) participants. Tapering was compared against complete rest (detraining), and all participants completed both conditions in a counterbalanced fashion. Overall during the 10 day progressive taper training volume was reduced by 72% (reducing the number of sets each training day), but the intensity of training remained unchanged. After the taper, statistically significant improvements occurred in peak torque during MVIC of the elbow flexors (6.8%; ES, 0.35) and non-statistically significant improvements in maximal low-velocity isokinetic peak torque of the elbow extensor force also occurred (2.8%; ES, 0.11) compared with baseline. However, maximal low-velocity isokinetic peak torque of the elbow flexors had statistically significant higher values 2 (4.3%; ES, 0.18), 4 (7.7%; ES, 0.31), 6 (4.9%; ES, 0.20) and 8 (3.2%; ES, 0.13) days into the taper. MVIC peak torque also had statistically significant higher values 2 (5.3%; ES, 0.27), 4 (4.1%; ES, 0.21), 6 (7.5%; ES, 0.38) and 8 (6.1%; ES, 0.31) days into the taper. These results show that a short-duration progressive taper in which volume is reduced but intensity kept high is able to improve strength of the elbow flexors, and can so do in as little as 2 days.

Izquierdo et al. (85) performed a 4-week taper after 16 weeks of resistance training in 11 national Basque ball players. This study also had 2 further groups involved, these were a complete rest ( $n = 14$ ) and a control group ( $n = 21$ ). The taper involved progressive lowering of training volume while intensity was increasing. Specifically, training at 90-95% of 1RM (3-4RM) during the taper, for 2-3 sets of 2-3 repetitions for all exercises; compared with 85-90% of 1RM ( $\approx$ 5RM) for 3 sets of 2-4 repetitions for all exercises immediately before the tapering period. The taper resulted in statistically significant improvements in 1RM bench press (2%) and half squat (3%), no changes were observed in the control group. These data showed that a longer duration progressive taper that reduces volume and increases intensity is able to improve performance in dynamic multijoint compound exercises.

The literature reviewed in this article seems to indicate that tapering is effective at increasing measures of maximal strength (36, 56, 63, 85). This has been shown to occur during both 1-step and progressive tapers, with no studies yet to directly compare types of tapering to determine the optimal method. As various measures of strength and many training methods have been followed, practitioners should be cautious with drawing definitive conclusions. However, there appears to be a trend that maintaining or increasing training intensity during the taper has greater benefits when compared with studies, which reduce the intensity (56, 63, 85). In all studies, volume was reduced (by 30-70%, through reduced training frequency or training session volume) which, if intensity is maintained or increased, is essential to reduce training load. Therefore, it may be hypothesized that a taper that maintains or increases training intensity while decreasing training volume is most effective for enhancing maximal strength. More research directly comparing methods of tapering for maximal strength is required to confirm this.

### **3.2.2 Mechanisms of Tapering on Maximal Strength**

Maximal muscular strength maintenance or improvements that occur during a taper must be the result of physiological changes. Specific changes within the muscular

and/or nervous system are likely to be responsible for performance changes. Several studies have investigated potential mechanisms (36, 56, 63, 85, 184).

Changes in the musculature may be influenced by alterations in the hormonal or biochemical profile of an individual. Testosterone and growth hormone are anabolic hormones known to enhance anabolic processes and protein synthesis within the body, whereas cortisol is released in response to stress and is catabolic, the ratio of the testosterone to cortisol therefore can be used to provide some indication of whether the body is in an anabolic or catabolic state (92). Coutts et al. (36) noted that the testosterone to cortisol ratio had statistically significant decreases during the 6-week overload training period, and there was no statistically significant change after the taper (also, no statistically significant changes were observed in either testosterone or cortisol). Creatine kinase, which is a biochemical marker associated with muscle damage (32), was seen by Coutts et al. (36) to have statistically significant increases after training and was then significantly reduced during a 7-day taper. Low levels of plasma glutamine, high levels of glutamate, and a decreased glutamine to glutamate ratio have been associated with a state of overtraining (135, 149). Coutts et al. (36) found that plasma glutamate showed statistically significant elevations and the glutamine to glutamate ratio showed statistically significant decreases after the training period; after the taper, these changes reversed. However, no statistically significant changes were seen in glutamine concentration throughout the study. Taken together, these changes may indicate that although an anabolic hormonal profile was not produced, muscle recovery was still able to take place during the 1-week tapering period.

Izquierdo et al. (85) measured hormonal changes during their 4-week progressive taper after 16 weeks of resistance training. No statistically significant changes were seen at any time during the study for total testosterone, free testosterone, cortisol or growth hormone. However, insulin like growth factor-1 (IGF-1) remained decreased (compared to pretraining) during the taper, and IGF-binding protein-3 (IGFBP-3) had further statistically significant increases after the taper. IGF-1 is known to increase protein synthesis in strength training and so enhance muscular hypertrophy (92), therefore, a sustained decrease may indicate that protein synthesis is still suboptimal

during the taper. However, IGFBP-3 is involved in regulating the availability of IGF's and extend the circulation of IGF's within the body (92). These changes did not occur in the detraining group who showed decreases in performance, so it may be hypothesized that even with decreases in IGF-1, the increases in IGFBP-3 may play a role in improving performance, potentially through other growth hormone metabolites or pulsatile releases of growth hormone not measured in this study.

Changes in muscle architecture or muscle mass may have potential to play a role in improving performance during the taper, as these have been shown to improve performance after periods of resistance training (49). Izquierdo et al. (85) noted that tapering participants maintained statistically significant reductions in body fat levels during a 4-week taper, whereas those who simply stopped training did not. This was not seen for a 1-week taper (63); however, this timeframe is likely too short for changes in body composition to occur. Zaras et al. (184) observed no changes in muscle architecture (vastus lateralis thickness, pennation angle or fascicle); however, the 2-week timeframe to observe such changes was probably too short given that such changes have usually been observed after extended periods of training (2, 89). They did, however, observe that an increased lean body mass from the training period was maintained, during both LT and HT. These observations suggest that tapering allows for maintenance of increased lean mass gained from prior training, but a taper period is likely too short a time period to have direct effects on muscle architecture or increases in muscle mass.

Nervous system changes may play a major role in increased maximal strength after a taper (65). Hakkinen et al. (63) observed statistically significant increases in the average maximum integrated electromyography (for 3 quadriceps muscles together) together with the increased MVIC peak force for the competitive powerlifters undertaking 1 week of reduced tapering; however, this was not seen for the noncompetitive lifters. This finding suggests that in well-trained athletes, a 7-day period of reduced training may improve neural activation and is associated with improvements in force output. No statistically significant changes in motor unit activation (using the interpolated twitch technique), time to peak torque or maximum rate of torque development were found by Gibala et al. (56) following a 10-day taper,

suggesting minimal or no contribution of the nervous system to their results. However, they concluded that motor unit activation may have been too insensitive to detect neural changes and that integrated electromyography may have been a better technique to use. Results from these 2 studies are inconclusive; more research is needed to determine whether improved neural activation plays some role in improved performance following a taper.

More research is needed to determine the mechanisms responsible for improved maximal strength after a taper, with very limited data currently available. However, it seems that hormonal and neuromuscular changes are minimal during short-duration tapers and that recovery of damaged muscle fibers may play a larger role in performance improvements. Maintenance of muscle mass during the taper along with repaired muscle may be 1 explanation for improved performance. However, because of the lack of research in this area, it is difficult to draw any clear conclusions.

### **3.3 Training Cessation**

Training cessation occurs when training completely ceases but regular daily activities still occur. It is also commonly referred to as detraining. Strictly speaking, short-term cessation is not true detraining, because in some cases, it can result in improved performance (112) and therefore can be classified as a type of tapering. In contrast, detraining is defined as a loss of training-induced adaptations after training cessation and so results in decreases in performance (112). Training cessation can only be differentiated by the length of time someone ceases to train; improved or maintained performance is only seen with short durations because training adaptations can be maintained. Table 3.2 shows a summary of the studies discussed in the following section.

**Table 3.2:** Effects of short-term training cessation on muscular strength

Study: Author	Subjects	Training history	Performance tests for maximal strength	Training duration before training cessation (d)	Duration of training cessation (d)	Change in performance vs pre- training cessation value (% change, effect size) ↑↑ = statistically significant change ↑ = non-statistically significant change
Anderson and Cattanaach (5)	n = 41 (22 men, 19 women)	NCAA Division I track & field athletes	1RM BP and SQ	35	2, 4 or 7 – randomly assigned, distribution not given	↑ 1RM BP & SQ - combined mean of 4.9% improvement for all groups and lifts
Gibala et al. (56)	n = 8 men	≥ 1-yr resistance training	LVIC and MVIC of elbow flexion	21	10	↓↓ LVIC of elbow flexion (-8.1%, 0.34) ↓ MVIC of elbow flexion (-1.9%, 0.13)
Hortobagyi et al. (82)	n = 12 men	Strength trained for 8.1 (SD±1.61) yrs; four powerlifters, eight Div 1 American football players	1RM BP and SQ, MVIC of knee extension and flexion, LVIC of knee extension and flexion	0 – stopped regular training for study	14	↓ 1RM BP (-1.7%, 0.12) ↓ 1RM SQ (-0.9%, 0.05) ↓ MVIC knee extension (-7%) ↓ LVIC knee extension (-2.3%) ↔ MVIC & LVIC knee flexion (data not available)
Izquierdo et al. (85)	n = 14 men	National level Basque ball players	1RM BP and SQ	112	28	↓↓ 1RM BP (-9%) ↓↓ 1RM SQ (-6%)
Terzis et al. (162)	n = 11 men	Physical education students	1RM BP, SQ and LP	98	28	↓ 1RM BP (-4.3%) ↓ 1RM LP (-5.7%) ↓ 1RM SQ (-3.9%)
Weiss et al. (173)	n = 54 men	Sedentary	1RM HR, LVIC of plantar flexors	56	2 (n = 13), 3 (n = 14), 4 (n = 13) or 5 (n = 14)	1RM HR: 2 ↑ (0.10) LVIC: 2 ↓ (-0.07) 3 ↑ (0.30) 3 ↑ (0.15) 4 ↑↑ (0.38) 4 ↑ (0.19) 5 ↑ (0.09) 5 ↑ (0.08) <i>Note, 4 days rest was significantly higher than 2 and 5 days, no other conditions.</i>
Weiss et al. (174)	n = 25 men	≥ 1.5 years strength trained	1RM BP, LVIC BP	28	2 (n = 8), 3 (n = 5), 4 (n = 5) or 5 (n = 7)	1RM BP: 2 ↑ (0.15) LVIBP: 2 ↑ (0.12) 3 ↑ (0.08) 3 ↓ (-0.11) 4 ↑ (0.03) 4 ↑ (0.26) 5 ↑ (0.07) 5 ↑ (0.07)

ES calculated using SD of the initial value before taper.

BP = bench press; HR = heel raise; LP = leg press; LVIC = low-velocity isokinetic concentric contraction; MVIC = maximal voluntary isometric contraction; RM = repetition maximum; SQ = back squat.

### 3.3.1 Effects of Training Cessation on Maximal Strength

When training cessation has occurred for no more than a week improvements, or maintenance, in maximal strength have often been observed. Anderson and Cattanaich (5) found small (combined mean of 4.9%) and non-statistically significant improvements in 1RM bench press and squat strength when 41 track and field athletes (22 men, 19 women) had 2-7 days off training following a 5-week strength training program. This study showed that 1RM strength can be maintained when only a short period of time is taken off training in trained athletes. Weiss et al. (173) also investigated the effects of short duration training cessation, between 2 and 5 days, and its effects on strength in the 1RM heel raise and maximal low-velocity isokinetic torque of the plantar flexors. Fifty-four untrained participants were involved in the study and before training cessation had completed 8 weeks of resistance training of the plantar flexors. It was observed that all durations of complete rest had only trivial ES except for 1RM heel raise strength at 3 and 4 days of training cessation, which had a small ES (0.30 and 0.38, respectively). These results again showed strength can be maintained with short periods of training cessation, and perhaps, 4 days of training cessation may be beneficial for maximal strength expression in untrained participants.

A follow-up study was conducted by Weiss et al. (174) using more ecologically valid strength measures of a 1RM bench press and maximal low-velocity isokinetic force of the bench press with 25 strength-trained participants. Almost all variables again, regardless of condition, had trivial ES following training cessation periods. The only exception to this was the maximal low-velocity isokinetic force of the bench press at 4 days of training cessation (ES = 0.26); however, 1RM bench press did not show this same trend. Again it was seen that training cessation for short durations had minimal impact on maximal strength expression, but perhaps, 4 days off training may have a greater positive impact on maximal strength as seen by the small ES observed. Training cessation for 2-7 days seems to have no negative impact on performance, allowing for maintenance of performance and potentially small improvements.

Longer durations of training cessation are less likely to have positive effect with detraining a more likely outcome. Gibala et al. (56) had 8 resistance trained (>1 year)

participants complete 10 days of training cessation after 3 weeks of resistance training. After 10 days of training cessation, maximal low-velocity isokinetic peak torque of the elbow flexors showed statistically significant reductions (-8.1%; ES, 0.34) and MVIC peak torque of the elbow flexors was also reduced (-1.9%; ES, 0.13); however, this was not statistically significant. Measures were also taken every 2 days during training cessation. Maximal low-velocity isokinetic peak torque of the elbow flexors showed statistically significant increases after 2 days (4.7%; ES, 0.21), and non-statistically significant increases after 4 days (1.7%; ES, 0.07) of training cessation, while all other time points showed reductions. MVIC peak torque was nearly identical at 2 (0.1%; ES, 0.01) and 6 (0.2%; ES, 0.01) days of training cessation. At 4 days of training cessation, there was a small non-statistically significant increase in MVIC peak torque (1.3%; ES, 0.09). All other time points showed non-statistically significant reductions in MVIC peak torque. These results show that in trained participants, 10 days of training cessation of the elbow flexors reduces maximal strength, but 2-6 days off training may allow for improvements or maintenance of maximal strength. Hortobagyi et al. (82) had 12 strength-trained athletes ( $8.1 \pm \text{SD } 1.61$  years of resistance training experience) cease their regular training for a 14-day period. Small reductions were seen in 1RM bench press (-1.7%; ES, 0.12), 1RM squat (-0.9%; ES, 0.05), MVIC peak force of the knee extensors (-7%) and maximal low-velocity isokinetic concentric torque peak force of the knee extensors (-2.3%), however none of these values were statistically significant. The knee flexors showed no statistically significant changes for either MVIC peak force or maximal low-velocity isokinetic concentric peak force. Such results demonstrate that 2 weeks of training cessation may be enough to cause reductions in performance.

As training cessation continues for up to 4 weeks, the magnitude of detraining effects is increased. Terzis et al. (162) had 11 physical education students perform 14 weeks of resistance training followed by 4 weeks of detraining. After statistically significant improvements in strength during the training period (22.1-32.9%), non-statistically significant reductions occurred in all 1RM values following the 4-week period of training cessation; 1RM bench press (-4.2%), leg press (-5.7%) and squat (-3.9%). Izquierdo et al. (85) performed 4 weeks of training cessation after 16 weeks of resistance training in 14 national Basque ball players. This study also included a taper ( $n = 11$ ) and a control group ( $n = 21$ ). Four weeks of training cessation resulted in

statistically significant reductions in 1RM bench press (-9%) and squat (-6%) performance. Together, these 2 studies show that training cessation of 4 weeks is enough to cause reductions in strength performance.

With more than 4 weeks of training cessation, only significant reductions are seen, clearly showing these durations to simply be detraining. Reductions back to pretraining values have been observed in previously untrained participants who ceased training for 3 months after an initial 3-month training period (where MVIC peak force of the knee extensors showed significant statistical increases by 16.7%) (4). Following 10-18 weeks of training with 12 weeks of training cessation resulted in a statistically significant reduction of 68% in MVIC peak force of the knee extensors (59).

Short durations of training cessation have been shown to maintain or produce small improvements in maximal strength and could be used as part of a taper. It seems that 2-6 days of training cessation is most likely to result in improved performance or will allow for maintained strength (5, 56, 173, 174); however, 10-14 days of training cessation results in small reductions in performance (56, 82). One month or more of training cessation will result in significant decreases in strength performance and is not advised as a method of tapering (4, 59, 85, 162).

### **3.3.2 Mechanisms of Training Cessation on Maximal Strength**

As with the mechanisms of tapering and regular training, the major physiological changes resulting in changes in maximal strength from training cessation are most likely to occur from changes in the muscular and/or nervous system (49). Several studies have looked at these mechanisms.

Hortobagyi et al. (82) noted changes in several anabolic hormones and other biochemical markers after 14 days of training cessation with growth hormone, testosterone, and the testosterone to cortisol ratio showing statistically significant increases, whereas cortisol and creatine kinase showed statistically significant decreases. These results may indicate the body is in an enhanced state of tissue remodeling and repair after 2 weeks of training cessation; however, maximal strength

performance was only maintained within this study. After 4 weeks of detraining Izquierdo et al. (85) observed no statistically significant changes in total testosterone, free testosterone, growth hormone, or cortisol. A tendency ( $p = 0.07$ ) for elevated IGF-1 was observed, which may indicate reduced stress of training and an enhanced anabolic environment. However, this study did not show favorable changes in other anabolic hormones, such as growth hormone, and performance also decreased.

Hortobagyi et al. (82) also reported non-statistically significant decreases in peak surface electromyography activity (-8.4-12.7%) of the vastus lateralis after 14 days of training cessation. Gibala et al. (56) saw no statistically significant changes in motor unit activation (using the interpolated twitch technique), time to peak torque or maximum rate of torque development after 10 days of training cessation, indicating no change or reductions in neuromuscular activation. In addition, Hortobagyi et al. (82) found that type I and II fiber areas decreased, but this was only statistically significant for the 6.4% (ES -0.30) decrease in the type II fiber area and not the 5.2% (ES, -0.26) decrease in type I fiber area. Terzis et al. (162) also observed a statistically significant decrease in the cross-sectional area of type II fibers (IIA and IIX) by 10-12% after 4 weeks of training cessation. These results indicate that type II fibers reduce in size after training cessation, with greater losses seen after longer durations of training cessation. Kadi et al. (88) have shown that the number of satellite cells remains elevated at 3, 10 and 60 days of training cessation after 3 months of heavy resistance training in previously untrained participants. This indicates that the muscle is in a state of, or capable of, growth or repair at these times following training cessation.

Hortobagyi et al. (82) found no statistically significant changes in body mass or body fat percentage after 14 days of training cessation; however, body fat percentage did show a small and non-statistically significant increase (2.6%). Terzis et al. (162) also found no statistically significant changes in body mass, fat-free mass or body fat percentage after 4 weeks of training cessation; again though a small (non-statistically significant) increase was seen in body fat percentage (3.0%), which was mirrored by a small reduction in fat free mass (-0.9%). These results suggest that a small decrease in lean mass may be associated with the small decreases in performance seen within these studies.

Given that few studies have looked into each of these many areas it is difficult to draw conclusions on the mechanisms for changes in maximal strength performance during periods of training cessation. Although it appears that when training ceases for a short duration, the body is in a better hormonal state for repair and growth. There is also a lack of studies investigating these changes within the first week of training cessation, which is when positive changes in performance are most likely to occur. Neural activation of the muscles may be reduced or unchanged, which would result in decreased performance, but it is not known whether this may be enhanced during the first week of training cessation when performance improvements are seen; further research is needed.

### **3.4 Conclusions**

Tapering is an effective strategy to enhance maximal muscular strength. Step and progressive tapers have both been shown to be effective following differing training methods before the tapering period. Reductions in training volume (by 30-70%, through reduced training frequency or training session volume) with maintained or small increases in training intensity seem to be most effective for improvements in maximal muscular strength. The optimal magnitude of such changes is not clear; more research is needed to determine this. Training cessation may also be able to play a role in enhancing maximal strength, with less than 1 week of training cessation being optimal for performance maintenance, and 2-4 days appearing to be optimal for enhanced maximal muscular strength. Improved performance may be related to more complete muscle recovery/repair, greater neural activation (with maintained muscle mass) and maybe an enhanced anabolic environment. Further research is required to gain a more complete understanding of optimal tapering for expression of maximal muscular strength; particularly, in the areas of optimal type of taper, the magnitudes of volume and intensity changes during the taper, and mechanisms causing enhanced strength.

### 3.5 Practical Applications

Given that training prior to a taper can differ significantly, recommendations will need to be adapted by practitioners and greater reductions in training load (and perhaps longer taper durations) implemented if an athlete has been undergoing a heavy training load. However, practitioners should ensure a taper duration of at least 1 week and no more than 4 weeks using a step or progressive taper. Reductions in training load should come primarily from total training volume. Reductions of 30-70% seem to be effective; this can be reduced through decreasing individual training session's volume and/or reducing the frequency of training. Intensity of resistance training should be either maintained at the pretaper level or slightly increased. Training should cease at least 2 days before the targeted competition/event, but no more than 1 week prior (Table 3.3).

**Table 3.3:** Tapering recommendations for maximal strength

<b>Taper variable</b>	<b>Recommendation</b>
Type	Step or progressive
Length	One to four weeks
Volume	Decrease by 30-70%
Intensity	Maintain or slightly increase
Training Frequency	Maintain or reduce to attain volume reductions

## CHAPTER FOUR

### TAPERING PRACTICES OF NEW ZEALAND'S ELITE RAW POWERLIFTERS

This chapter consists of the final peer reviewed manuscript version of the following article published in the *Journal of Strength & Conditioning Research*:

Pritchard H, Tod D, Barnes M, Keogh J, and McGuigan M. Tapering practices of New Zealand's elite raw powerlifters. *Journal of Strength & Conditioning Research* 30(7): 1796-1804, 2016.

#### Preface

The previous chapter provided research based recommendations for the strength taper. Given that these guidelines are based on limited research, the practices of elite strength athletes may provide further insights into effective tapering strategies. This chapter utilised a qualitative approach to determine the tapering practices of elite powerlifters. The findings from this chapter may be of use to athletes in strength sports, as well as provide areas for further investigation, or inclusion, within the later training studies in the thesis.

#### 4.1 Introduction

Powerlifting is a strength sport that includes three barbell based lifts: the squat, bench press and deadlift. The major governing body is the International Powerlifting Federation (IPF) who sanctions competitions in accordance with the World Anti-Doping Agency (WADA) code. The objective of the sport is to lift the largest combined weight across the three lifts during competition (46). Swinton et al. (158) investigated the training practices of elite British powerlifters and found nearly all athletes implemented some kind of periodization into their training. Like most athletes, powerlifters will target specific competitions during the competitive year for maximal performance, so this periodized training must culminate with an effective taper to ensure peak performance.

Tapering is the last stage in a well-planned training program and has the ability to determine the success or failure of the training period prior to competition (79). Mujika and Padilla (112) have described tapering as a nonlinear reduction in the training load over a period of time which reduces the stress, or fatigue, of training while improving fitness to achieve optimal performance at a specific time. Tapering will usually result in a performance improvement of around 3% (range of 0.5-6%), which in some sports could be the difference between winning and not making the podium (97, 127). It has been shown that a taper of less than four weeks with volume reductions of around 50-90%, maintaining or slightly increasing training intensity, whilst maintaining training frequency is most effective for experienced endurance and anaerobic athletes (179). An athlete who is fatigued requires a longer tapering duration and greater training load reductions (163). However, there is currently limited specific tapering research examining powerlifters and other strength sports.

Research that has investigated tapering for strength has shown that when intensity is maintained or slightly increased during the taper greater performance improvements may occur (56, 63, 85). In these studies training volume reductions of 30-70% occurred through reduced training frequency or training session volume over a period of one to four weeks (124). It may be hypothesized that a taper maintaining or increasing training intensity, while decreasing training volume, is an effective strategy for enhancing maximal strength. However, it is unknown if the strategies currently employed by strength athletes agree with the current literature. If athletes' practices are similar to research supported recommendations this would provide further confirmation to coaches and practitioners that these strategies should be adopted. It is also possible that athletes' may employ strategies that differ from the literature yet are successful, if so this would require further investigation.

The major aims of this study were to gain some insight into the current tapering strategies of elite powerlifters, why such strategies are employed, how these strategies were developed and how tapering might differ for each lift. Insights from this study will provide useful information on peaking strategies which can be applied by strength coaches and athletes. Results from this study may also help athletes from

other sports optimize their strength, and competitive sports performance – especially those who are well strength-trained.

## **4.2 Methods**

### **Experimental Approach to the Problem**

Semi-structured interviews with elite raw IPF powerlifters in New Zealand were used to collect data needed to achieve the aim of the study. Semi-structured interviews ensured information surrounding people's experiences of tapering could be obtained, which may be missed with alternative methods (such as surveys) that predetermine the type of data collected. Previous research has revealed that semi-structured interviews and surveys can capture elite athletes' and coaches' experiences and practices in ways that allow others to learn from their experiences (164, 180, 181). To ensure current elite powerlifters were recruited for the study, the criteria for an invitation to participate was the achievement of a raw competition total (combination of athletes' best squat, bench and deadlift) classified as 'elite' by the New Zealand Powerlifting Federation's (NZPF) raw lifting qualification standards within the 12 months prior to the commencement of this investigation (see Table 4.1 for NZPF standards). Competitions run by the NZPF are sanctioned by the IPF and comply with the WADA code. No athletes interviewed had failed drug tests, ensuring results are applicable to drug-free athletes. As the participant pool was limited, the aim was to have as many lifters as possible participate in the study. Our initial target was to get at least 10 participants, then as many additional participants above this number as possible – a total of 11 lifters from various weight classes completed the study. Sample sizes in studies using qualitative methods are often of a similar size because of the depth of data collected from each individual (164). In such studies the focus is on understanding a few individuals in depth rather than gaining a superficial understanding of many people (164). Nevertheless, given that there were 16 individuals who may be classified as New Zealand elite lifters at the time of data collection, our sample represents 70% of the total population. Raw (or classic) powerlifting was chosen because it is performed without the aid of specialized supportive equipment (46) and so findings can be considered more appropriate to athletes from other sports.

**Table 4.1:** NZPF elite total standards

<b>Weight Class</b>	<b>NZPF Elite Total Standard</b>
<b>Men</b>	
53kg	432.5kg
59kg	482.5kg
66kg	522.5kg
74kg	575kg
83kg	645kg
93kg	687.5kg
105kg	730kg
120kg	780kg
120+kg	800kg
<b>Women</b>	
43kg	237.5kg
47kg	277.5kg
52kg	305kg
57kg	335kg
63kg	355kg
72kg	365kg
84kg	387.5kg
84+kg	397.5kg

To ensure we obtained relevant data from our semi-structured interviews we obtained answers to a specific set of guiding interview questions, however, these questions allowed some freedom for participants to discuss related information and experiences they felt relevant to their tapering practices. Questions asked were designed to ensure we collected data that would answer our research questions – determining general (and lift specific) tapering strategies, how such strategies were chosen and the reasons for strategies employed. Following pilot testing on two international powerlifters, the questions were refined before being used for data collection.

### **Subjects**

Prior to commencing the research, the study was approved by the Auckland University of Technology Ethics Committee. Sixteen possible New Zealand powerlifters met the 'elite' total standard so were identified and contacted via email to participate in the study, eleven athletes responded to volunteer and subsequently participated in the

study (representing 70% of the total population). Nearly all of those who didn't participate simply did not respond to the invitation to participate, while some stated they would rather not be involved in the study due to time commitments or other, undisclosed, reasons. Prior to involvement in the study, all participants received written explanations of the study's risk and benefits and provided informed consent.

The participants (eight men, three women) had a mean age of  $28.4 \pm 7.0$  years, best competition total (within 12 months of the study) of  $615.5 \pm 158.1$  kg, best Wilks score (within 12 months of the study) of  $431.9 \pm 43.9$  points, competition bodyweight of  $91.0 \pm 27.4$  kg and trained  $4.8 \pm 0.5$  days per week. The eight men had a mean age of  $26.5 \pm 5.4$  years, best competition total of  $693.8 \pm 97.8$  kg, best Wilks score of  $450.3 \pm 31.9$  points and competition bodyweight of  $94.9 \pm 29.9$  kg. The three women had a mean age of  $33.3 \pm 9.6$  years, best competition total of  $406.7 \pm 39.9$  kg, best Wilks score of  $382.6 \pm 32.5$  points, and competition bodyweight of  $80.4 \pm 19.4$  kg. The Wilks score is a bodyweight adjusted scoring system which allows comparisons in weight lifted across weight classes (46). All participants had previously achieved medals at IPF International Competitions (minimum of Oceania Championships). Nine participants said they were self-coached, and two said they were semi-coached (i.e. a coach had some input but was not in full control of their training).

### **Procedures**

All participants were initially approached via email. The email outlined the study's aims, risks and benefits, and invited athletes to participate in the study. It also gave participants information regarding the types of questions that would be asked, and a chance to ask any questions of the researcher prior to their involvement. Giving participants such background information means that they have a chance to reflect on their practices and improves the value of data collected. After providing informed consent, interviews were arranged; eight interviews occurred via telephone (or Skype voice calls) and three face to face. Interviews took 30-60 minutes to complete and were recorded using a Sony integrated circuit recorder (Sony IC Recorder ICD-AX412F, Sony Corporation, Tokyo, Japan). Throughout the interview the researcher also took notes on participants' responses. Following the interview, recordings were transcribed verbatim. Telephone interviews allowed data to be collected from all suitable

participants without the issue of location. It has been shown that telephone interviews produce comparable quality and scope of data as face to face interviews while improving participation rates (157).

Aside from initial demographic and performance based questions, all guiding interview questions were based around participants' training practices and in particular how they taper, or peak in the final few weeks of training before an important competition. Many of the questions asked were open ended which gave participants the freedom to discuss what they thought was relevant to their tapering practices (120), while some questions allowed specific quantitative information on their tapering strategies to be determined (such as training volume, intensity and frequency etc.). The questions asked during interviews are shown in Table 4.2.

**Table 4.2:** The questions the participants were asked during the interviews

1. When do you perform your final training sessions for each competition lift and what weights are used? Why?
2. When do you perform your final 'heavy' (>80% 1RM) training sessions for each competition lift and what weights are used? Why?
3. Length of standard taper and why?
4. How does your volume, intensity and frequency change from pre to post taper?
5. How far out from an event do you begin to drop total training volume? And intensity? Does this differ according to the lift?
6. How do you determine to alter the loads, reps etc. as you do?
7. Do you remove your assistance exercises or training equipment (belts, wraps etc.)? If so, when and what do you remove? Why?
8. When tapering hasn't worked, what went wrong and why?
9. Is there any other information on your tapering or training practices that you think may be of interest?

### **Statistical Analyses**

Where data were quantifiable (such as training volume, intensity and frequency etc.) descriptive results were calculated for the sample. T-tests were used to determine

differences between each lift (paired, two tailed t-test). Significance was set at  $P \leq 0.05$ . Where significance was found, effect sizes (ES) were also calculated (47). Hopkins' scale for determining the magnitude of ES was then used to describe magnitudes (81); these were: trivial 0-0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large  $>2.0$ . Analysis was performed using computer software (Excel; Microsoft Corporation, WA, USA).

Qualitative data was subjected to a thematic content analysis following Patton's (120) guidelines as used with previous data collected from a strength and conditioning context (164). A similar approach has also been used elsewhere within sport science literature (137, 171). Raw data units were arranged into common themes that address the research question. Specifically, the researchers read through the interview transcripts to find information related to the guiding interview questions and then summarized the information under labels that reflect the content of the theme. Themes addressed the overall research questions. Frequencies of specific themes were determined to help establish the number of people in this sample providing similar responses to interview questions. Themes were classified according to the representativeness shown, as performed by Tod et al. (164). Classifications were: *general*, themes applying to all or all but one participant; *typical*, themes applying to more than half the participants, but less than general; *variant*, themes applying to two or more participants, but less than typical.

### **Validity and Reliability**

Three types of triangulation (38) were used to establish validity and reliability within this study. Firstly, participants across many weight classes and from many regions throughout New Zealand were recruited for the study and expressed similar themes, showing external validity in that similar themes emerged amongst these individuals. Secondly, member checking – providing participants with the researchers' interpretations of their data (38) – also occurred, ensuring that participants agreed that the results reflect their realities. Participants had both their own transcripts and interpretations of themes from all participants returned to them. No participant reported that we had misinterpreted or misrepresented them in their transcripts or our subsequent interpretations, with only minor wording corrections were required in

two participants' transcripts. Thirdly, critical peer review – or analyst triangulation – occurred in that two other people (aside from the lead researcher) with expertise in differing areas evaluated the results and agreed that the themes expressed were representative of the data collected.

### 4.3 Results

#### Quantitative Data

Participants generally followed a linear periodized approach with volume reducing and intensity increasing nearer to competition. Total training volume peaked  $5.2 \pm 1.7$  weeks from competition while average training intensity (of 1RM) peaked  $1.9 \pm 0.8$  weeks from competition, with the heaviest individual session (where the highest intensities, %1RM, are used) around  $2.3 \pm 0.7$  weeks out from competition. As a competition approached the focus became predominately on competition lifts, with both squat and deadlift accessory work removed  $2.0 \pm 0.7$  weeks from competition and bench press accessory work removed  $1.9 \pm 0.7$  weeks from competition.

Participants stated that their taper length was  $2.4 \pm 0.9$  weeks out from competition. During this taper, participants stated that they maintained training intensity, however they estimated that volume was reduced by  $58.9 \pm 8.4\%$  during the taper. The final week was often a drastically reduced “deload” week with reductions in both volume and intensity, with training frequency reduced to  $34.7 \pm 14.2\%$  of usual training frequency and the final weight training session performed  $3.7 \pm 1.6$  days out from competition. A tapering timeline for subjects is shown in Figure 4.1.

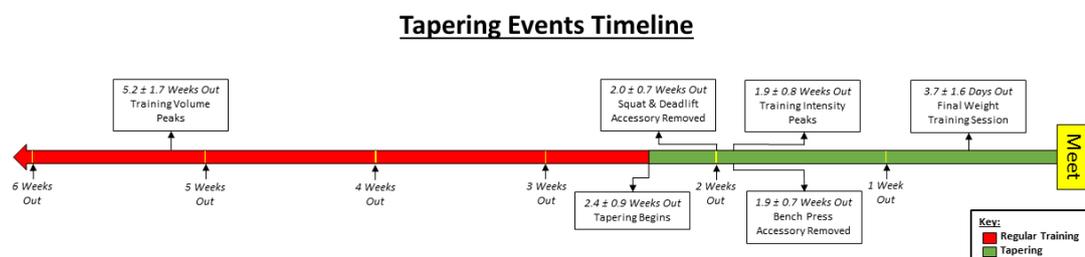


Figure 4.1: Tapering events timeline

Table 4.3 shows the final ‘heavy’ (>80% of 1RM) training session for each competition lift, as well as the final training session – regardless of weight – for each competition

lift. Statistically significant differences were seen in that the final deadlift training session was performed further from competition than the relevant squat or bench press sessions (both moderate ES = 1.13 and both P = 0.004), the final heavy deadlift training session was performed further from competition than the relevant heavy squat (moderate ES = 0.85 and P = 0.005) or heavy bench press sessions (moderate ES = 1.09 and P = 0.003), and also, the final heavy bench press session was performed at a higher relative intensity than the final heavy deadlift session (small ES = 0.56 and P = 0.033; this also approached significance when compared to the final heavy squat session, small ES = 0.40 and P = 0.057).

**Table 4.3:** Final training sessions

<b>Final Training Session Type</b>	<b>Days Out from Competition</b>	<b>Top Set(s) Percentage of 1RM</b>
Final heavy squat session	8.0 ± 2.9 *	90.0 ± 5.4
Final squat session	4.0 ± 1.8 *	66.0 ± 15.7
Final heavy bench press session	7.3 ± 2.7 *	92.2 ± 5.7 #
Final bench press session	4.0 ± 1.8 *	67.3 ± 18.1
Final heavy deadlift session	10.9 ± 4.0	88.9 ± 6.1
Final deadlift session	7.4 ± 4.1	72.6 ± 18.5
* denotes significant difference compared to relevant deadlift session; # denotes significant difference compared to relevant deadlift session. Note: Heavy means >85% of 1RM.		

### **Qualitative Data**

Table 4.4 presents the broad themes and subthemes from the interviews related to the research aims and their sample representativeness. Italicized quotes below illustrate participants' views and the number in brackets represents the percentage of participants who expressed that theme.

**Table 4.4:** Broad themes and subthemes from the interviews and the sample representativeness

<b>Theme</b>	<b>Sample Representativeness * (% of sample)</b>
Tapering differences between lifts More recovery needed for the deadlift Bench press & squat tapering performed in a similar manner Bench press can stay heavier for longer	General (90.9%) Variant (45.5%) Variant (36.4%)
Information sources for taper strategy Trial & error By ‘feel’ Previous coaches Other lifters	Typical (81.8%) Typical (63.6%) Variant (36.4%) Variant (18.2%)
Motives for tapering strategy To fully recover Light competition movements for familiarity Time off heavy work makes them ‘hungry’ to lift	General (90.9%) Variant (45.5%) Variant (18.2%)
Taper focus is on the competition lifts Accessory work is removed during the taper Equipment is used on heavy sets as it would be in competition	General (90.9%) Typical (81.8%)
Other strategies employed during the taper Nutrition Mobility Work - stretching, foam rolling, massage etc.	Typical (72.7%) Variant (45.5%)
Poor tapering experiences Taking too much time off – 1 week+ Over exertion too often prior to taper Cut too much weight	Typical (54.5%) Variant (36.4%) Variant (36.4%)
General = themes applying to all or all but one participant; typical = themes applying to more than half the participants, but less than general; variant = themes applying to two or more subjects, but less than typical. Note: Participants could be included in more than one subtheme, hence totals may add to more than 100%.	

### **Tapering differences between lifts**

*More recovery needed for the deadlift* (90.9%). Almost all participants commented that the deadlift required a longer recovery period before competition. Generally they felt that “it takes longer to recover, it’s harder on the body” and “it will be the one I tend to be most sore from so I need an extra couple of days”. As well as requiring the most

days off, participants also felt this wasn't an issue because it *"is probably not a movement I feel like I am going to forget or loose the groove for and I don't want to run the risk of taxing the body in any way"* and that *"you can go a couple of weeks without doing it and it's really not going to make much of a difference"*, indicating that the deadlift takes longer to recover from, while potentially requiring less frequent training.

*Bench press & squat tapering performed in a similar manner (45.5%).* Almost half of the participants followed similar tapering strategies in both their bench press and squat, such as *"my last training session is usually squat and bench press, at my starting [competition opening] numbers"*, *"I would work up to an opener... about a week out for a squat... [final heavy bench press session is] one week out at opener"* and *"I will do the bench press and the squat together [8 days out] and the deadlift will be on its own [two weeks out]"*. This approach is an extension on the fact that the deadlift takes longer to recover while the other two lifts do not seem to have the same fatiguing effects.

*Bench press can stay heavier for longer (36.4%).* In contrast to the above, some participants felt that the bench press can stay heavier until closer to competition than the other lifts. Statements such as *"I feel like it is a stronger lift and I can handle it a little closer to the comp... I can bench heavy and two days later bench heavy again"* and *"I do tend to keep that [bench press] quite heavy right up to close and keep that intense"* showed that some participants appear to have little issues recovering from heavy bench press.

### **Information sources for taper strategy**

*Trial & error (81.8%).* Generally participants had come up with their tapering strategies through their own failures in the past. It wasn't normally based on scientific information but *"has come about by trial and error"*. They commented things such as they *"guess it's just trial and error. It seems to be working, what I am doing"* and others that over time they have *"learned through all the competitions just how long it takes me to feel good again or how long my body needs to recover"*. This trial and error, or learning through past experience, was expressed by nearly all participants.

By *'feel'* (63.6%). Often lifters may have a set plan but they adjust it as needed. Some participants said after harder training than expected that *"I feel like I need the rest to get myself ready"* and others that *"I have learnt how to read my body"*, and so adjust their taper accordingly. Through past experiences they have learnt how to adjust their taper based on how their body feels. They may make changes within a training session during the taper depending on how they feel or how previous training has gone, *"purely on what I feel"*. This was a typical theme, the ability to *"adjust the program leading up to the competition"*.

*Previous coaches* (36.4%). Although at the time of the study only two participants had input from a coach, several had been previously coached and expressed that their original tapering strategies were formed then. Some were told *"to rest for that time frame and that has worked for me when I have listened"*, others stated *"he [the coach] would lead the way and how to taper and tell me when I needed to stop training and gave me a bit of a start to see how it feels to train different ways"* and simply *"it was my old coach in Perth – it was his logic"*. In essence coaches led initial tapering strategies which were then adjusted to what worked through trial and error.

*Other lifters* (18.2%). There were a few participants who commented that *"it was when I first came into powerlifting that was how everyone did it"* and *"it was because someone else told me to do it"*. Interestingly both of these lifters later changed their tapering strategy because what they were told worked didn't work well for them.

### **Motives for tapering strategy**

*To fully recover* (90.9%). Nearly all participants expressed the view that reducing training load during the taper was to allow for full recovery. Comments such as *"resting up and getting my muscles back to 100%"*, *"you don't need that loading, you have done all the hard work it is more maintaining the weight you are lifting without doing overload training. So you recover more"*, *"trying to achieve maximum recovery"*, *"giving my body enough time to recover"* and *"I generally feel like giving my body a break and just let it recover"*. Clearly, recovery during the taper is a major motive in order to improving performance in competition.

*Light competition movements for familiarity (45.5%).* Lifters typically expressed the need to continue to do the competition movements to keep them familiar. This was made clear through statements such as *“I realized that I needed to keep working a little bit more into these meets so didn’t feel as lethargic”, “I have to do the light movement a few days out”* and *“still feeling like the movements are familiar and that I still know the groove for that particular exercise”*. Continuing to do competition movements appears to be imperative to keep the body and mind focused on the movements.

*Time off heavy work makes them ‘hungry’ to lift (18.2%).* A couple of participants expressed that by avoiding heavy work they feel excited and ‘hungry’ to lift on competition day. One stated that *“by the time Saturday comes I feel really good, I am hungry for the weight”*, while the other said *“part of it is a mental thing, that amount of time is about how long it takes me to get really excited about an event and to lift again”*.

#### **Taper focus is on the competition lifts**

*Accessory work is removed during the taper (90.9%).* During the final stages of training nearly all participants expressed that they remove the accessory, or non-competition, movements: *“none of them [final heavy training sessions] have accessories in them”, “I take it [accessory work] out two weeks out for all three lifts”, “I remove all assistance work three weeks out”* and *“I drop all of them [assistance lifts]”*. One participant stated that they remove these lifts to ensure they can *“go in and train the heavier weight [on competition lifts]”*, showing that this change is to allow the focus to be on the three competition lifts.

*Equipment is used on heavy sets as it would be in competition (81.8%).* Typically participants stated that they train like they will compete when lifting heavy sets during the taper. When asked if they alter equipment (wrist wraps, knee sleeves etc.) use, typical responses were *“I use it all”, “I try and keep everything similar to what I have on comp day”* and *“everything you are going to use in competition”*. The focus was on doing things like they will be done on competition day, as one participant put it, *“practicing my routine”*.

### **Other strategies employed during the taper**

*Nutrition (72.7%). Many participants undertook changes in their nutrition. Changes were made that they believed assisted recovery “I am tracking my food, I am trying to get a 40/30/30 [carbohydrate, protein, fat] split that seems to make me feel good and recover quicker”; improved performance “normally my training is at a maintenance level of calories and I will add in another 10% on top of that leading to a competition”, “cutting out caffeine for a week – just to get maximum advantage come competition day”, “always have a good carb feed that night and try get another one the night before competition”; helped lower bodyweight “I slowly fluctuate [bodyweight] down and then miss the odd meal that I don’t feel like I need, like I will have a workout then just have a few eggs or something after it”; and, general health “I change my diet leading to a competition, I go 100% gluten free about six weeks from a competition, I’m a little bit gluten intolerant so I cut all gluten out of my diet”.*

*Mobility Work - stretching, foam rolling, massage etc. (45.5%). One theme expressed by participants was the use of mobility work for recovery. Some participants said “I would normally have a massage about 2-3 days out from competition”, “I will do some [foam] rolling out or sometimes I go and get a massage. I do try to stretch out and [keep] mobile during that time”, “I will do full a full on mobility session afterwards [light training week of competition], just to keep myself moving” and “I need the recovery time to let every muscle heal as much as possible, I do mobility stuff, stretching stuff during that week”. Mobility work took various forms but with the same goal, to assist recovery and keep the body moving.*

### **Poor tapering experiences**

*Taking too much time off – 1 week+ (54.5%). A common theme was that when things had gone wrong, too much time had been spent away from training. This was expressed as participants said things such as “everyone just stopped training seven days out. So I did that for my first few comps and then after learning about my body a bit more I realized that I needed to keep working a little bit more into these meets so I didn’t feel as lethargic.”, “one week out I didn’t lift at all. It was because someone else told me to do it and it didn’t work.”, “I just didn’t train for the whole week before and I*

*didn't like that*" and *"tapering too soon or backing off the weights too soon"*. These theme echoes the earlier theme of the need for keeping movements in for familiarity.

*Over exertion too often prior to taper* (36.4%). Several participants expressed that tapering did not work when *"I hit too many peaks through the build-up in nine weeks of training... there was no linear progression"* or *"a week later I had weight lifting nationals so doubling the two sports ruined my taper"* and *"whenever anything has gone wrong it is because I have pushed too hard on my last sessions"*. These participants tried to go too heavy too early and so broke the progression or fatigued themselves before meet day arrived, resulting in poor performances.

*Cut too much weight* (36.4%). Cutting weight is often required for powerlifters to compete in lower weight categories, and it is also a cause of much stress and sometimes poor performances. Several participants stated things to that effect such as *"I think one year it was because I was dropping weight"*, *"everything went wrong because I had to cut too much weight"* and *"it is something else to think about as well, it is another stress to add to the equation. You are constantly thinking about weight all the time"*. Although not all participants who cut weight expressed this, a few did, it was particularly an issue when too much weight had to be cut, and one participant said they performed a *"four week cut to get from 80kg to 74kg – it was horrible"*.

#### **4.4 Discussion**

The current study is the first to document the tapering strategies employed by elite powerlifters. Participants reduced training volume but kept intensity relatively high, with a competition lift focus during the taper. It was generally believed by the participants that the deadlift requires a longer recovery, and the focus of a taper is on achieving full recovery with accessory work being removed. Typically participants stated that (a) trial and error and changes based on 'feel' were the information sources of tapering strategies chosen, (b) during the taper lighter competition movements are kept to maintain movement familiarity, (c) equipment used during the taper is the same as in competition, (d) nutrition is manipulated during the taper and (e) poor tapering occurs when too long (one week or more) is taken off training.

The final training session was performed at  $3.7 \pm 1.6$  days out from competition, with eight of the eleven participants performing their final session three days out from competition, this is similar to previous research focused on other populations (173, 174). Weiss et al. (173, 174) have demonstrated on two occasions that approximately four days off training may be most beneficial for optimizing strength performance. In their initial study, Weiss et al. (173) had 54 untrained participants train their plantar flexors for eight weeks before testing 1RM heel raise and maximal low velocity isokinetic torque of the plantar flexors following short term training cessation. The only groups showing positive ES (enhanced performance) larger than trivial were three and four days of training cessation which showed small ES (0.30 and 0.38, respectively). Their follow up study (174) involved 25 strength trained participants who trained for four weeks prior to testing 1RM bench press and maximal low velocity isokinetic force of the bench press following short term training cessation. Only one absolute strength measure in one condition, maximal low velocity isokinetic force of the bench press at four days of training cessation, showed a greater ES than trivial, with a small ES of 0.26. These results show some harmony between previous research and the current elite participants' trial and error-based practices, that three to four days of strength training cessation may be optimal for maximal strength expression.

Nearly all participants (90.9%) removed accessory - or assistance, i.e. non-competition – exercises during the taper period, around two weeks out from an event. This serves two roles; firstly it reduces a large portion of training volume (participants in the current study lowered their training volume by nearly 60%) which will allow for recovery from fatigue as part of the taper, and secondly, it acts to ensure training during the tapering period is competition focused and specific. Drastically reducing training volume during the taper has been shown to be an appropriate strategy to enhance recovery and to optimize performance across a range of sports (111, 124, 179). The major goal in tapering for the overwhelming majority of participants (90.9%) was to recover; this aligns with thoughts of previous researchers who have stated that the tapers primary aim is “to allow for physiological and psychological recovery from accumulated training stress” (115). Although training must be reduced to allow for recovery, some training should occur during the taper to avoid a loss of strength (56,

82, 111). The need for an appropriate level of training during the taper was also reinforced in the current study as many participants (54.5%) felt that poor tapering occurred when too much time was taken off from training. The training performed during tapering by our participants was on exercises that occur on competition day, so it is very specific, and this follows periodization principles which recommend specific training of lower volume near competition (122). If this same strategy is to be applied by athletes in other strength-related sports this would suggest that these athletes may benefit from performing strength exercises which directly assist aspects of sports performance when lowering training volume during the taper.

An interesting finding, that confirmed anecdotal reports, was that elite powerlifters require longer to recover from the deadlift than the other two competition lifts. Our findings showed that 90.9% of the elite powerlifters interviewed said the deadlift took longer to recover from and they also had their final deadlift session further out from competition than their final bench press and squat sessions to gain additional recovery time. However, no research was available that demonstrates it takes longer to recover from the deadlift than other compound movements. Interestingly, several elite powerlifters believed it was helpful to keep the bench press heavier prior to competition. Perhaps this additional recovery time for the deadlift is due to the absolute load of the deadlift being heavier, and so applying a greater stress to the body – especially the lower back (30), or a greater reliance on larger lower body muscle groups. However, no evidence is currently available to support these hypotheses. These findings require more research, but it may be prudent that athletes be cautious in programming the deadlift near competitions.

Another novel finding extending current knowledge was that trial and error was involved in informing most participants' tapering strategy; that is learning how to taper from making mistakes or through past experiences of tapering. Such an approach could be enhanced through the use of a training log or diary to monitor athletes training and responses to tapering (48). Training diaries would allow athletes to more accurately reflect upon their tapering practices following competitions and make changes when strategies do not work, as well as replicate aspects that have successful results. Many participants interviewed in the current study used diaries to record their

training information and utilized these when providing us with their training and tapering data. Reflection in athletes has been shown to occur more commonly amongst top performers (86); this may explain why some of the elite lifters (63.6%) in the current study had an ability to change training during the taper based on 'feel', as they have reflected on previous experiences of how their body responded during tapering. Recommended tapering strategies can act as a guide, however, because individuals may have differing responses to strategies or come from different training backgrounds that could influence these responses (111), reflection will also allow individual's responses to be determined and implemented in future tapers. This strategy could also be implemented with other strength sports athletes; they could trial recommended strategies and use reflective practices to determine which methods were useful in improving performance following the taper. The large number of athletes utilizing trial and error as a learning strategy reinforces the need for further research to guide athletes in optimal tapering strategies (i.e. changes to training intensity, volume, frequency etc.) for maximal strength performance, the best ways to reflect on such training, as well as how to use science to communicate to specific populations.

The results from this research may assist strength athletes in planning their taper, however, some limitations exist within the present research. Only elite raw New Zealand powerlifters were recruited in the current study, so different strategies may potentially be seen in lifters from other nations or from those who compete at a different level. Results may apply directly to powerlifting, a pure strength sport, but must be interpreted and modified to suit other sports where strength may not be the sole focus.

#### **4.5 Practical Applications**

Although the results of this study are specific to tapering for powerlifting, several of the findings have implications for other sports that benefit from strength training. For strength sports it would seem that athletes should not completely remove strength training prior to an important event, instead they should reduce the volume of strength training while keeping the intensity relatively high. Strength and conditioning

coaches need to be aware that if too long of a time period is taken off strength training then force expression, and therefore performance, may decrease. If strength is to be optimized, specific to the sporting event, coaches should remove non-specific strength training exercises during the taper. Strength and conditioning coaches should prescribe only primary movements that directly assist sports performance in the strength program near an event, to assist with reduction in fatigue while maintaining/improving strength expression and performance. However, practitioners need to be careful to avoid going too heavy too often (over exertion or testing strength) prior to a competition as this may impair competitive performance. Coaches should potentially avoid deadlifting maximally close to important events as this may have some negative effect on recovery. Finally, coaches and athletes could make use of training diaries to more accurately track their sessions and changes in training load over the course of a training program. Such information can be used as the basis of reflective practice to help competitors optimize their tapering routines.

## CHAPTER FIVE

### SHORT TERM TRAINING CESSATION AS A METHOD OF TAPERING TO IMPROVE MAXIMAL STRENGTH

This chapter consists of the final peer reviewed manuscript version of the following article in press with the *Journal of Strength & Conditioning Research*:

Pritchard H, Barnes M, Stewart R, Keogh J, and McGuigan M. Short term training cessation as a method of tapering to improve maximal strength.

*Journal of Strength & Conditioning Research* DOI: 10.1519/

JSC.0000000000001803.

#### **Preface**

Within Chapter Three, training cessation was discussed as a potential method of improving maximal strength. Furthermore, Chapter Four revealed that short periods of training cessation are undertaken by elite powerlifters prior to important events. This chapter investigated the effectiveness of two different durations of short term training cessation on maximal strength, following a strength training period designed using Chapter Two's recommendations. The findings from this chapter can be applied, within the context of a taper, to ensure athletes take sufficient rest prior to an event while avoiding detraining.

#### **5.1 Introduction**

Short-term training cessation is when an athlete ceases training for a short period of time whilst continuing with everyday activities (124). It has also been referred to as detraining, however because it can result in improved performance in the short term it does not conform strictly to the definition of detraining (112). Short term training cessation is sometimes undertaken as part of a taper (or as an alternate taper method) prior to an important event. Currently, little is known regarding the best duration of implementing training cessation during the taper. A better understanding of optimal durations, as well as understanding the mechanisms behind its effects, will assist

exercise scientists and practitioners in effectively prescribing tapering practices for strength athletes.

Weiss et al. (173) investigated the effects of short term training cessation on exercise performance in 54 young male participants by training the seated heel raise movement three days per week for eight weeks. Participants showed significant improvements in isokinetic plantar flexor and one repetition maximum (1RM) seated heel raise strength following the training period. Participants were then split randomly into four groups which either ceased training for two, three, four or five days following the training period. The results showed that 1RM heel raise had small improvements at three (Effect size (ES) = 0.30) and four (ES = 0.38) days of training cessation in untrained participants, compared to only trivial improvements at other durations of training cessation. The four days of training cessation also had statistically significant improvements compared to two or five days of training cessation. Additionally, a small ES was also seen for isokinetic torque at 1.05 rad/s following four days of training cessation (ES = 0.19) and a moderate ES for isokinetic torque at 3.14 rad/s following four days of training cessation (ES = 0.57), with only trivial ES for other durations.

A follow up study by Weiss et al. (174) had 25 strength trained males follow a periodized plan for four weeks, focused on heavy upper body resistance training. Participants were tested for their isokinetic bench press at moderately fast (1.49 m/s) and slow (0.37 m/s) velocities and 1RM bench press immediately following their four weeks of training and after two, three, four or five days of training cessation (depending on the group they assigned to). No significant changes were seen, however, maximal low velocity isokinetic force of the bench press showed small improvements in ES at four days of training cessation, with only trivial changes observed for other training cessation periods and tests. Anderson & Cattanach (5) also found small improvements in 1RM bench press and squat strength when 41 track and field athletes had two to seven days off training following a five week, three days per week strength training program.

These results (5, 173, 174) are somewhat consistent with the findings of Pritchard et al. (126) who reported that elite powerlifters usually take  $3.7 \pm 1.6$  days off prior to

important competitions. Together these studies suggest that short durations of training cessation can maintain, or perhaps even improve, strength performance. However, to date no studies have investigated the mechanisms behind the maintenance, or improvement, in performance observed during short term resistance training cessation, its effects on lower body muscle groups or used strength trained populations as participants.

Several studies have investigated longer durations of training cessation (greater than one week), where performance was more likely to be only maintained or reduced (82, 85). These studies typically also examined the anabolic hormonal and biochemical profile, noting reductions in markers of muscle damage and improved anabolic state during the cessation of training (82, 85). It has also been observed in longer duration training cessation studies that surface electromyography (EMG) and associated muscular performance decreases (non-significant) after two weeks of detraining (82). Therefore, improvements in performance during short duration training cessation may be related to improvements in neuromuscular activation and anabolic profile, which has yet to be studied. If training cessation results in improved neuromuscular activation or a more anabolic environment, this may result in improved strength performance due to greater motor unit activation or an increase in muscle mass and, thus, enhanced force output.

The aim of this study was to investigate the effects of different durations of training cessation on both upper and lower body maximal strength performance in resistance trained males. Additionally, the mechanisms underlying cessation related performance changes were explored. We hypothesized that training cessation will improve maximal strength, of both the upper and lower body, and that changes in hormonal profile, EMG and/or mood states will be associated with these positive changes in physical performance. It was also hypothesized that 3.5 days of training cessation would be more beneficial than 5.5 days.

## **5.2 Methods**

### **Experimental Approach to the Problem**

This crossover trial study was designed to determine the performance effects and mechanisms underlying the effects of different durations of training cessation on maximal strength in resistance trained men. Specifically, participants were randomly assigned to either 3.5 days (84-hours – condition A) or 5.5 days (132-hours – condition B) of training cessation following four-weeks of strength training. This ensured participants had a similar style of training prior to training cessation, ensuring the effects of the training cessation could be determined from a similar fatigue state.

Participants were familiarized with all testing procedures at least 48-hours prior to any experimental testing. Participants reported to the lab fasted, at the same time ( $\pm 30$  min), in the morning for testing prior to each four-week training period (T1), within 12 hours prior to each final training session (T2), and immediately following each training cessation period (T3). On each visit to the lab, participants provided a saliva sample, a finger-prick blood sample, completed two psychological surveys. Tests were performed to capture information related to physiological and psychological that may impact performance. Following these tests, performance tests (vertical jump, mid-thigh pull (MTP) and isometric bench press (IBP)) on a force plate. EMG was measured on MTP and IBP. These variables were chosen to determine the effects on maximal strength performance and neuromuscular function.

Following the first post-cessation testing, participants were given a 7-10 day “wash-out” period after which they completed another four-weeks of training followed by the other cessation intervention. The eight participants who completed the study did so in a counter-balanced fashion.

### **Subjects**

Prior to commencing the research, the study was approved by the Auckland University of Technology Human Ethics Committee. All participants were informed of the benefits

and risks of the investigation prior to providing written informed consent, before beginning any testing procedures. Inclusion criteria were: (i) participants current deadlift 1RM of at least 1.5 times bodyweight (BW), and (ii) two or more years of resistance training experience. 13 men, who met the inclusion criteria, volunteered and were recruited as participants within this study, however, due to various reasons, only eight completed the study.

The eight participants who completed the study were aged  $23.8 \pm 5.4$  years, had a body mass of  $79.6 \pm 10.2$  kg, a height of  $1.80 \pm 0.06$  m and a relative deadlift 1RM of  $1.90 \pm 0.30$  times BW at the commencement of the study.

### **Testing Procedures**

*Strength Testing.* Within one week of beginning the study, participants were tested for their 1RM on all powerlifts (squat, bench press and deadlift) according to NSCA guidelines (61). Participants were also tested for 2-8RM on all other lifts programmed (see program in Table 5.1) to determine estimated 1RM on lifts that may be unfamiliar. Estimated 1RM was determined using the formula:

$$1RM = \text{Load} / (1.0278 - 0.0278 * \text{Reps Performed}) \quad (24)$$

1RM testing was repeated during the “wash-out” period in order to establish training loads for the subsequent, second four-week training period. This testing occurred at the same time of the day ( $\pm 1$  hour) on both occasions.

**Table 5.1:** Four week training overview

Day	Exercise	Week One			Week Two			Week Three			Week Four		
		Sets	Reps	% 1RM	Sets	Reps	% 1RM	Sets	Reps	% 1RM	Sets	Reps	% 1RM
1	Bench Press	3	4	80	3	4	82.5	4	3	85	4	3	87.5
1	Back Squat	4	6	75	4	6	77.5	4	4	80	4	4	82.5
1	Military Press	4	6	75	4	6	77.5	4	4	80	4	4	82.5
1	Barbell Row	3	10	70	3	10	72.5	4	8	75	4	8	77.5
2	Deadlift	3	4	80	3	4	82.5	4	3	85	4	3	87.5
2	Close Grip Bench Press	4	6	75	4	6	77.5	4	4	80	4	4	82.5
2	Deficit Deadlift (2")	4	6	75	4	6	77.5	4	4	80	4	4	82.5
2	Good Morning	3	10	70	3	10	72.5	4	8	75	4	8	77.5
3	Back Squat	3	4	80	3	4	82.5	4	3	85	4	3	87.5
3	Paused Bench Press	4	6	75	4	6	77.5	4	4	80	4	4	82.5
3	Front Squat	4	6	75	4	6	77.5	4	4	80	4	4	82.5
3	Barbell Row	3	10	70	3	10	72.5	4	8	75	4	8	77.5

Note: CG = Close Grip; 2ct Paused Bench = 2 second pause at the bottom of a bench press.

*Endocrine and Biochemical Measures.* Participants fasted from the previous evenings meal prior to testing sessions, this meal was noted and participants were instructed to replicate this meal the evening before each testing session throughout the study. Participants were instructed to avoid resistance exercise and minimize all exercise for 48 hours prior to each lab testing session (except for T2, as prescribed training was performed within this time frame), and to avoid all exercise for at least 24 hours prior to the testing session. All testing sessions occurred at the same time in the morning ( $\pm$  30 min) throughout the study. Water consumption was allowed ad-libitum prior to each testing session to ensure participants arrived hydrated.

Participants were immediately seated upon arrival at the lab, given 250ml of water to drink and instructed to relax for five minutes. After this rest period, participants produced (through passive drooling) a saliva sample of at least 2 mL into a 10 mL polypropylene collection tube (LabServ, Thermo Fisher, New Zealand). Salivary concentrations of testosterone and cortisol have been shown to be independent of flow rate (134). Samples were immediately separated into two polypropylene micro-centrifuge tubes (LabServ, Thermo Fisher, New Zealand) and placed on ice. Following the trial, samples were transferred to a freezer and stored at  $-80^{\circ}\text{C}$  until analysis. Analysis occurred in duplicate using commercial enzyme-linked immunosorbent assay (DRG International, USA) according to manufacturer's instructions. Coefficient of variation (CV) of duplicate samples was 3.3% for cortisol and 5.3% for testosterone.

Following saliva collection, a capillary blood sample was collected from a finger using aseptic technique. This blood sample was immediately analyzed to determine plasma creatine kinase (CK) activity using the Reflotron<sup>®</sup> systems spectrophotometer (Roche Diagnostics, Switzerland) which has typical CV of 3.5%. This method of CK analysis has been used previously in the literature to assess for indicators of muscle damage (83).

*Psychological and perception measures.* Participants completed a profile of mood states (POMS) (80) and daily analysis of life demands in athletes (DALDA) questionnaires (136). POMS was analyzed to determine total mood disturbance (TMD) score which represents all six specific mood states of the test. Previously, TMD scores

have been reported to indicate athletes that may be at risk of staleness (or overtraining) and so this score may indicate whether there is any impact of the training or recovery on a participants psychological state (80). A baseline for DALDA (frequency of 'worse than normal' results) was established in the initial two weeks of training and compared to changes following the training and training cessation periods (136). The tool has been used previously with strength athletes to monitor responses to intense training (156).

*Performance measure:* Participants performed a five-minute warm up at 70W on a cycle ergometer before performing normalization contractions for EMG, as outlined under 'Neuromuscular measures' section. Participants then performed practice CMJ's with hands on hips at 50%, 75% and 100% effort, followed by three recorded maximal CMJ's on a force plate (400 series, Fitness Technology, Australia) separated by approximately one-minute of rest. The force plate recorded at a rate of 600Hz for all performance tests. The best (based on jump height) of the three CMJ's was then analyzed using commercial software (Ballistic Measurement Systems (BMS), Innervations, Australia) to determine jump height and flight-time: contraction time. These results were used to measure the effects of training cessation on maximal power and neuromuscular function (34, 169). CV's were 2.9% for CMJ height and 3.3% for CMJ flight time: contraction time. Intra class correlations (ICC's) were 0.97 for CMJ height and 0.91 for CMJ flight time: contraction time.

The MTP was then performed on the same force-plate with the knees at 130° (whereby a knee angle of 180° represents full knee extension) and an upright torso using previously described methods (105, 106). Participants performed practice MTP's at 50%, 75% and 100% effort, followed by three recorded maximal MTP efforts of approximately five seconds on the force plate, separated by approximately one-minute of rest. Participants were instructed to pull as hard and fast as possible during each maximal effort. The best MTP (based on peak force) was analyzed to determine peak force and maximum rate of force development (mRFD). Peak force was the highest force recorded during the contraction, and mRFD was the maximum value calculated by dividing the change in force over the time interval. These values were automatically calculated using the BMS software for both MTP and IBP. MTP's have been used

previously in the literature and have shown strong positive relationships with dynamic 1RM performance, particularly of the lower body (105, 106). CV's were 3.2% for MTP peak force and 11.7% for MTP mRFD. ICC's were 0.97 for MTP peak force and 0.85 for MTP mRFD.

The IBP was then performed on the same force plate with the top end of the bench centered over the force-plate and the elbows at 90° flexion (if 180° is straight), hands were positioned no more than 81 cm apart (90). Participants performed practice IBP's at 50%, 75% and 100% effort, followed by three recorded maximal IBP efforts of approximately five seconds on the force plate, separated by one-minute of rest. Participants were instructed to push as hard and fast as possible during each maximal effort. The best IBP (based on peak force) was analyzed to determine peak force and mRFD as described for MTP. CV's were 4.6% for IBP peak force and 12.2% for IBP max mRFD. ICC's were 0.98 for IBP peak force and 0.88 for IBP mRFD.

*Neuromuscular measures:* Surface EMG of the vastus lateralis (VL) and triceps brachii (TB) were measured during MTP and IBP, respectively. The VL is a muscle that is easily accessible for EMG, and studies have shown that both throughout the entire deadlift and during the final 60° of knee extension VL activation is similar to or higher than several hamstring muscles making it a suitable muscle to measure during the MTP (42, 43). The TB is one of the agonist muscles during elbow extension and, as such, has a primary role during the bench press. Electrodes were placed according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations (74).

EMG was measured using 10 mm diameter gel filled Ag/AgCl electrodes (Blue Sensor, Medicostest, Rugmarken, Denmark) at a sampling rate of 1000 Hz via a PowerLab data acquisition system and analyzed in Chart for Windows (ADInstruments, Australia). The highest 1000ms average rectified EMG recorded during the greatest MTP or IBP was compared to the highest 1000ms average rectified EMG recorded during maximal activation of the VL or TB, respectively. Normalization of VL EMG was determined using the highest 1000ms average rectified EMG of three maximal five second isometric contractions of the quadriceps during a seated knee extension, with the knee

angle set at 90°, and for the triceps during a standing elbow extension with the elbow angle at 90°. This maximal activation testing occurred immediately following the cycle warm up. The average rectified EMG during MTP and IBP was reported as a percentage of the average rectified EMG value obtained from the MVC and referred to as normalized EMG. These results may give an indication of the neural input to the musculature at differing time points during the study and may provide an indication of whether changes in force are due to alterations in neural activation and neuromuscular efficiency (41, 98).

### **Training Protocol**

Following the first testing session participants commenced four-weeks of training (see Table 5.1) focused on the powerlifts. The program aimed to bring all participants into a similar phase of training and fatigue prior to training cessation. This training was designed using Prilepin's chart as a guide to sets and repetitions at specific training intensities and the specific program used has been shown to be effective at improving maximal strength (123). The program consisted of four exercises per day; the first exercise was one of the three powerlifting competition lifts (back squat, bench press and deadlift), the next two exercises were usually a variation of the powerlifts, with the final exercise being an accessory movement aimed at producing muscular hypertrophy of some of the primary agonists. Participants completed a DALDA questionnaire prior to all training sessions, as well as recording their training sessions within a training log. A minimum of one full day's rest was instructed between training sessions, i.e. if day one was on Monday then day two would be on Wednesday at the earliest. During the training periods participants were able to continue performing aerobic and sport training as per normal (but no other resistance training), however this was discontinued during the training cessation periods and 48hrs prior to each initial testing session. During the 'wash-out' period between conditions participants could train as they wished. Training compliance was 97.8% over the two training periods.

## Statistical Analysis

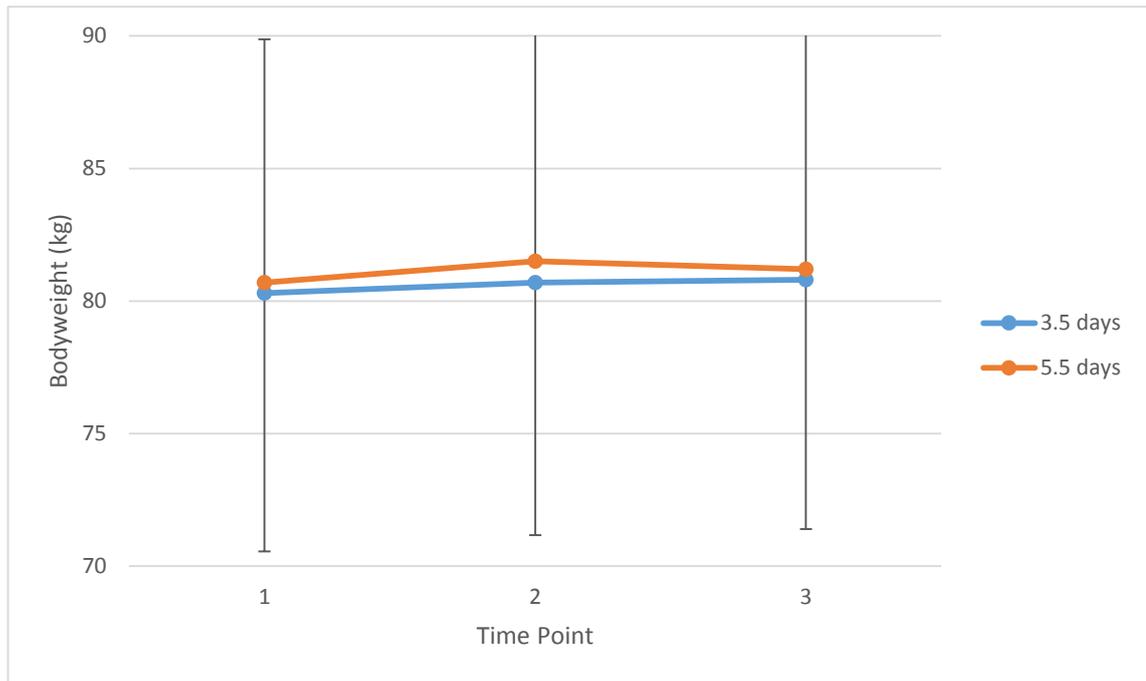
Two-way repeated-measures ANOVA were used to test for differences in psychological (TMD and DALDA), performance (peak CMJ power, CMJ height, CMJ flight-time: contraction time, MTP and IBP peak force, and, MTP and IBP mRFD) and neuromuscular measures (normalized EMG), between time points and training cessation conditions. Where a significant difference was determined by ANOVA, post-hoc paired comparisons were made using the method of Student–Newman–Keuls. Significance was set at  $P \leq 0.05$ . Analysis was performed using commercial computer software (Sigma Plot 11.0, Systat Software, Inc., Chicago, Illinois, USA).

ES of performance measures were calculated and interpreted as: trivial 0-0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large  $>2.0$  (81). CV's and ICC's for performance measures were calculated using the three maximal efforts recorded during T1 for the 3.5 days condition.

## 5.3 Results

Due to participant availability for final training, the 3.5 day and 5.5 day training cessation periods were  $3.68 \pm 0.12$  days ( $88.42 \pm 0.12$  hours) and  $5.71 \pm 0.13$  days ( $136.94 \pm 0.13$  hours) of training cessation, respectively.

Participants bodyweights increased over time ( $P = 0.022$ ), with post-hoc testing revealing a significant increase between T1 and T2 (0.85%,  $P = 0.036$ , with a trivial ES of 0.05) with no further change from T2 to T3. No difference in the changes in bodyweight were observed between conditions. Bodyweight changes are shown in Figure 5.1.



**Figure 5.1:** Bodyweight changes over time

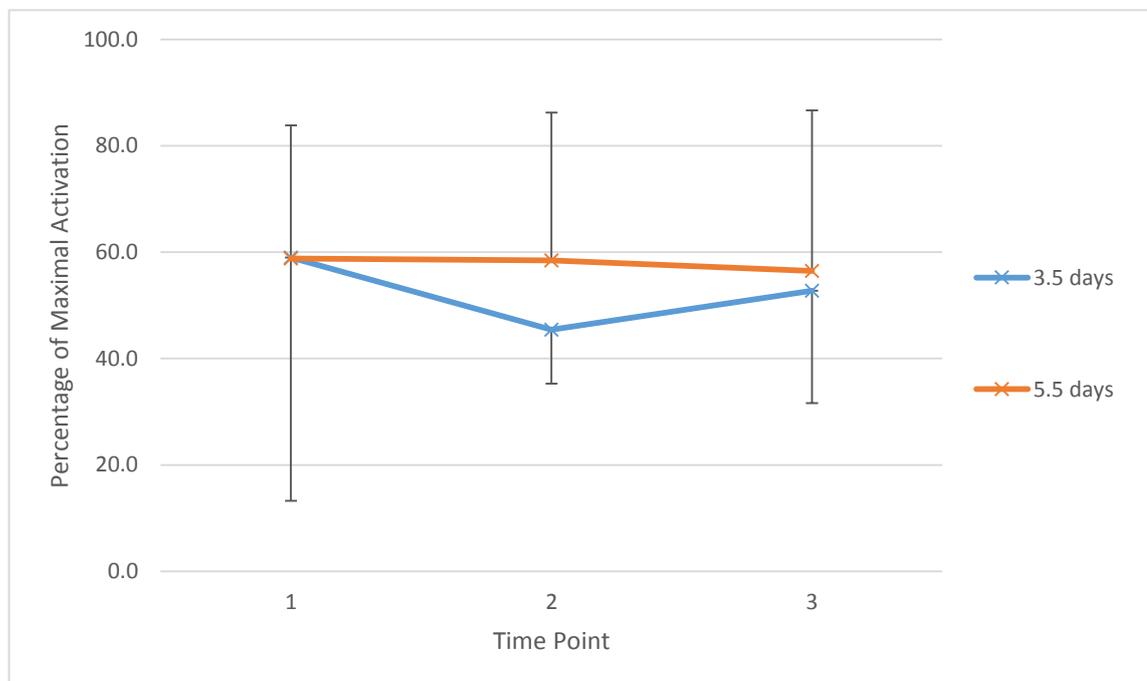
Table 5.2 shows the results of the performance tests. CMJ height showed significant increases over time ( $P = 0.013$ ) with post-hoc testing showing a significant increase from T1 to T3 ( $P = 0.022$ , with a small ES of 0.30). MTP relative peak force approached a significant increase over time ( $P = 0.068$ ) and no difference was found between training cessation durations ( $P = 0.682$ ). IBP relative peak force showed significant increases over time ( $P = 0.004$ ) with post-hoc testing revealing a significant increase from T1 to T3 ( $P = 0.011$ , with a small ES of 0.30). As with MTP, no difference between training cessation duration was found ( $P = 0.762$ ). No other significant differences were seen between any of the conditions for any of the performance measures made.

**Table 5.2:** Results of performance measures

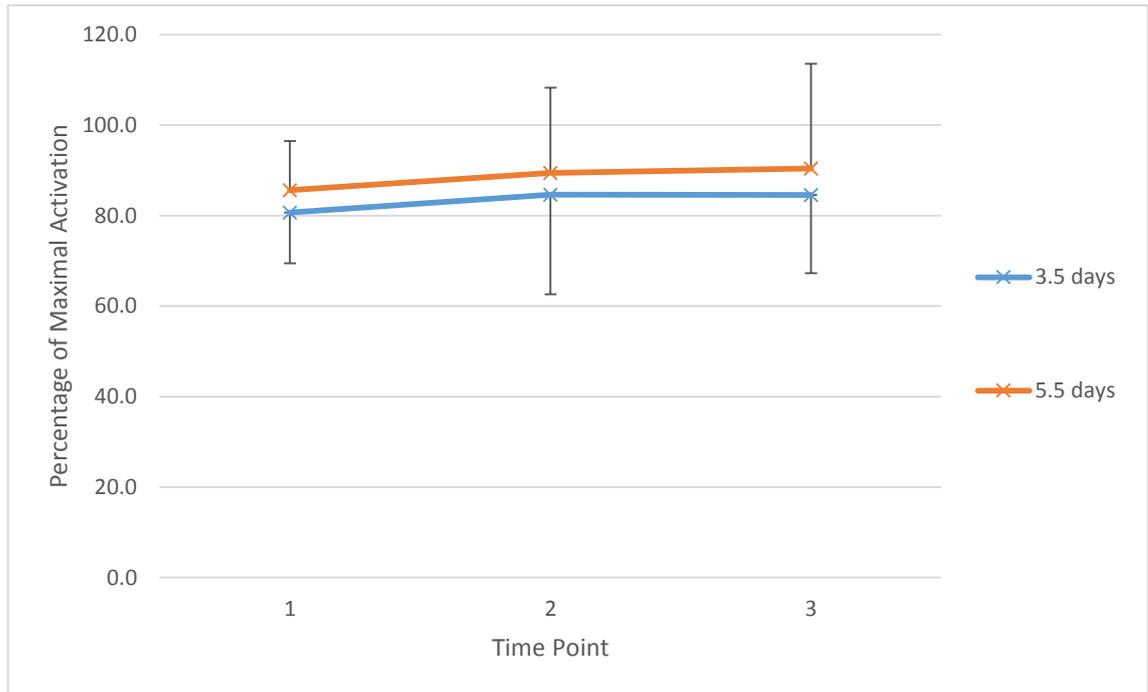
Trial	Counter Movement Jump		Mid-Thigh Pull		Isometric Bench Press	
	Jump Height (cm)	Flight Time : Contraction Time	Relative Peak Force (N/kg)	mRFD (N.s <sup>-1</sup> )	Relative Peak Force (N/kg)	mRFD (N.s <sup>-1</sup> )
A-1	37.7 ± 6.0	0.645 ± 0.068	37.3 ± 3.3	11248.4 ± 3594.1	18.5 ± 2.7	7801.3 ± 2297.0
A-2	37.7 ± 5.3	0.644 ± 0.082	38.3 ± 5.3	10206.4 ± 2480.6* <sup>1</sup>	19.5 ± 2.3* <sup>1</sup>	8533.9 ± 3255.4* <sup>1</sup>
A-3	39.4 ± 5.3* <sup>1,2</sup>	0.638 ± 0.061	39.1 ± 5.1* <sup>1</sup>	10386.0 ± 3033.5* <sup>1</sup>	19.8 ± 2.7* <sup>1</sup>	7850.6 ± 2956.0
B-1	37.3 ± 3.2	0.658 ± 0.089	37.7 ± 6.6	11758.1 ± 2565.6	18.8 ± 2.8	8418.9 ± 2925.6
B-2	39.2 ± 3.6* <sup>1</sup>	0.659 ± 0.085	38.8 ± 5.8	12061.6 ± 4762.1	19.6 ± 3.1	8627.2 ± 4962.4
B-3	39.8 ± 5.4* <sup>1</sup>	0.678 ± 0.114	39.7 ± 6.5* <sup>1</sup>	12811.0 ± 3181.4* <sup>1</sup>	19.8 ± 2.9* <sup>1</sup>	9449.5 ± 3040.3* <sup>1</sup>

Notes: Letters represent the condition, A = 3.5 days of training cessation condition; and, B = 5.5 days of training cessation condition. Numbers represent testing time points, 1 = pre-training; 2 = on the final day of training, 3 = following the respective training cessation period. \* indicates small ES vs time point of same condition, superscript number(s) indicates which time point.

No significant differences were seen at any time point during any condition for absolute or percentage changes in endocrine and biochemical measures (Table 5.3), DALDA ‘worse than’ scores, POMS TMD scores, or EMG results (Figures 5.2 and 5.3).



**Figure 5.2:** Vastus Lateralis EMG changes over time



**Figure 5.3:** Triceps Brachii EMG changes over time

**Table 5.3:** Endocrine and biochemical measures

	Salivary Cortisol (ng/ml)	Salivary Testosterone (pg/ml)	T/C Ratio (x1000)	Plasma Creatine Kinase (I/U)
<b>A-1</b>	5.90 ± 2.07	85.41 ± 28.43	16.53 ± 8.84	144.8 ± 83.5
<b>A-2</b>	5.38 ± 2.01	80.78 ± 26.84	16.21 ± 6.60	236.5 ± 156.2
<b>A-3</b>	4.62 ± 1.12	66.95 ± 11.68	14.84 ± 2.38	151.6 ± 84.2
<b>B-1</b>	5.71 ± 1.84	82.50 ± 16.99	15.38 ± 3.90	116.1 ± 53.8
<b>B-2</b>	5.41 ± 1.43	85.24 ± 23.28	17.81 ± 10.07	166.7 ± 63.0
<b>B-3</b>	4.83 ± 0.97	81.00 ± 20.36	17.53 ± 5.89	124.5 ± 84.2

## 5.4 Discussion

The present results indicate that strength training followed by short term training cessation improved performance more than strength training alone. Significant performance improvements, compared to pre-training, were observed for both CMJ height and IBP relative peak force following short term training cessation, this significant improvement was not present on the final training day. No training cessation period was shown to be more beneficial, indicating that both 3.5 and 5.5 days off training have similar effects on performance.

Anderson & Cattanach (5) and Weiss et al. (173, 174) had previously demonstrated that short durations of training cessation, of less than a week, were able to enhance, or at least maintain, strength following a period of strength training. Of these studies, only Weiss et al. (173) showed statistically significant increases in maximal strength, and this was only assessed for the plantar flexors of the ankle. The present study is the first to demonstrate statistically significant increases in multi-joint, upper body strength following a period of training cessation, when compared to training alone. These findings indicate that short term training cessation, as a form of taper, may be effective for enhancing strength of the upper body and maintaining strength of the lower body and could be implemented within a training cycle.

The current investigation did not show either period of training cessation to be more beneficial than the other. Neither 3.5 nor 5.5 days off training demonstrated any significant differences for any performance measure, and ES's were of similar magnitudes regardless of condition. To date only one study (173) has shown statistically significant improvements in maximal strength for a specific time period, with four – compared with two and five – days of training cessation improving maximal strength of the plantar flexors, while having similar ES's to three days. A similar period of time off training ( $3.7 \pm 1.6$  days), prior to competition, has been reported by elite powerlifters (126). Weiss et al. (174) showed small ES improvements at two and four days training cessation (compared with only trivial ES's for three and five days of training cessation). Similarly, Anderson & Cattanach (5) did not show any period from two to seven days to be more optimal at improving maximal strength. Therefore, it appears less than a week off training may be suitable for performance enhancements and/or maintenance with no particular time period more beneficial.

We observed that CMJ height increased following training cessation compared with pre-training values. As countermovement jumps are heavily reliant on the stretch-shortening cycle, efficient jumping performance may indicate that the neuromuscular system is functioning effectively (169). McLean et al. (107) and Twist et al. (170) have shown decreases in vertical jump performance (flight time) following competitive rugby league matches which was subsequently restored several days later. Twist et al.

(170) attributed this decrease in performance to two factors: decreased central drive (due to muscle soreness) and tissue damage disrupting calcium release to impair excitation contraction coupling. Therefore, it could be hypothesized that more efficient neuromuscular function (or less neuromuscular fatigue) allowed for better expression of maximal strength in the current study and may underpin the potential performance gains associated with short term training cessation.

Several other physiological changes occurred which may assist in explaining the performance changes observed. One such change was that bodyweight showed statistically significant increases over the training period (albeit by a small amount). Increases in bodyweight may indicate muscle mass was gained during the training periods. Although muscle mass was not directly measured, increases are commonly seen following strength training (99). Improvements in muscle mass could cause improvements in strength following training due to an increased size of muscle fibers and thus force production capacity (49). It was also interesting to note that, although not significant, T3 had lower cortisol values in both conditions, suggesting less stress following the training cessation periods (92). As no other significant changes were found for other biochemical, hormonal or neuromuscular measures, further investigation may assist to confirm this.

The current investigation confirms that a short period of time (less than one week) off training can have positive effects on maximal strength expression in resistance trained athletes. It may also indicate that such changes are due to more efficient functioning of a less stressed neuromuscular system. Wider research of the strength training taper is also lacking (124), such research should look to determine how altering the volume and intensity of strength training may affect the effectiveness of tapering in strength athletes.

## **5.5 Practical Applications**

Based on the current findings it is clear that short term training cessation could be used by strength and conditioning practitioners as an effective means of tapering to enhance expression of maximal strength. It is suggested that athletes take a minimum

of two days, but no more than a week, off from training prior to an important event where maximal strength expression may be beneficial, with around four days appearing to be optimal. Strength and conditioning practitioners should also consider the athletes previous training, as harder training periods may warrant longer periods of training cessation prior to events.

The findings also show that strength and conditioning coaches can design programs for their athletes where they may take short periods of time away from resistance training and be confident that athletes will maintain their previous levels of strength. Such a strategy could be applied as a planned recovery period in a training cycle, or when an athlete may have limited access to adequate training facilities.

## CHAPTER SIX

### EFFECTS OF VARYING INTENSITY DURING TAPERING ON MAXIMAL STRENGTH

#### Preface

The previous chapter demonstrated that following four weeks of strength training with a period of short term training cessation was effective in enhancing maximal strength and power. Chapter Three recommended volume reductions during strength tapers to improve maximal strength, while changes to intensity were less clear. This training study investigated volume reduced tapers, of increased or decreased training intensity, on maximal strength. The findings from this chapter can be utilised, along with those from earlier chapters, in guiding the taper design for strength athletes.

#### 6.1 Introduction

Effective tapering strategies will allow an athlete to express competitive performance enhancements from training, while poor tapering strategies may hinder performance. The primary objective of a taper is to minimise fatigue from training, allowing for expression of improved fitness and thus maximal performance at a specific point in time (97, 124). Reductions in training load define the taper, achieved primarily through alterations in training volume but also variations in training intensity. It is therefore imperative that training programmes have well planned tapering periods. Much of the literature regarding tapering has focused on performance in aerobic based or team sports (36, 40, 79, 113), with less research on strength performance (63, 184). However, it appears that for both aerobic or strength performance to be enhanced following a taper, training volume should be reduced while training intensity should be maintained or slightly increased (111, 124)(Chapter Three).

Reductions in training volume have been effectively utilised as a tapering strategy (56, 63, 100, 126). Hakkinen et al. (63) studied well trained (5-10 years) strength athletes who performed two weeks of dynamic strength training followed by one week of training with reduced (by 50%) volume. The strongest five participants showed a

significant increase in maximal force and EMG activity following the reduced training week, while the five others showed no changes. Gibala et al. (56) had eight participants, with at least a year of regular resistance training, perform three weeks of standardised elbow flexor training. Participants were then randomly assigned to a 10 day taper, or rest only group. Tapering involved reductions in volume (to 38% of the initial training volume) while maintaining training intensity. The taper significantly increased isometric peak torque compared to baseline, while low velocity concentric isokinetic elbow flexion peak torque was significantly greater when compared to the rest only group. Marrier et al. (100) implemented a three week volume reduced, 30% of total running distance in field sessions and 50% of sets for strength and high-intensity, taper following a four week pre-season training camp in international rugby sevens players. They found small improvements (qualitative difference *very likely small increase*) in isometric mid-thigh pull (MTP) and improvements in 30m sprint time (qualitative difference *almost certain large decrease*) from pre-training to peak values during the three-week taper. Chapter Four documented that elite powerlifters usually reduce volume by 58.9% while maintaining or slightly reducing training intensity (126). Together, these findings indicate that reducing training volume, while maintaining intensity, can be an effective tapering strategy in athletes with strength training backgrounds.

Alterations in intensity during the taper, compared to prior training, have also been investigated. Coutts et al. (36) had seven semi-professional rugby league players undertake six weeks of combined progressive overload training (resistance and field training) prior to a one week taper of reduced volume ( $\approx 55\%$ ) and a small reduction in intensity (based on perceived exertion). A significant increase occurred following the taper for isokinetic peak torque (at low velocity,  $1.05 \text{ rad}\cdot\text{s}^{-1}$ ) of both the knee extensors and flexors. Creatine kinase (CK) was reduced following the taper, while no hormonal changes occurred. Further, the testosterone to cortisol ratio was significantly reduced following overreaching (prior to the taper). Following 16 weeks of training, Izquierdo et al. (85) had 11 well trained Basque-ball players undertake a tapering period. Tapering involved four weeks of strength training of progressively reduced volume, while intensity increased from 90% 1RM to 90-95% 1RM. Both 1RM bench press and half squat increased significantly following the four-week taper. No

significant changes in hormonal measures were noted, except for resting serum insulin-like binding protein-3 which showed significant elevations. Tapering with reduced volume was again shown to result in performance improvements in trained populations, regardless of increases or decreases in training intensity. However, none of these studies directly compared differences in intensity during a volume reduced taper.

Zaras et al. (184) performed the only study to directly compare different training intensities during a strength training taper. Following 12-15 weeks of training, 13 throwers (seven male, six female) performed either a light or heavy two-week taper, using 30% or 85% of 1RM, respectively, before the other training and taper block. During the taper period, volume was reduced more with the light taper than the heavy taper. The heavy taper had significantly greater percentage increases in leg press 1RM and isometric peak force than the light taper. Muscle architecture (vastus lateralis muscle thickness, pennation angle and fascicle length) was not altered from either taper. This study indicated that tapers of higher intensities may be more effective for improving maximal strength. These findings are supported by the findings presented in Chapter Four where qualitative analysis showed that elite powerlifters usually maintain a high intensity of training when peaking for important events (126). It should be noted, however, that Zaras et al. (184) did not control training volume in each taper and therefore their reported enhancement of strength performance may be due to a combination of changes in training volume and intensity, not solely intensity.

Collectively these studies demonstrate that tapering can be an effective strategy to enhance maximal strength, but it remains unclear whether higher or lower training intensities are more beneficial if the reductions in training volume are equal. Therefore, using a strength-trained population, the aim of this study was to investigate the performance effects of different training intensities during a strength training taper with equal training volume reductions. The mechanisms behind such changes were also explored. It was hypothesised that a taper with increases in training intensity would result in larger increases in maximal strength compared to a taper which decreased training intensity.

## 6.2 Methods

### Experimental Approach to the Problem

This study employed a randomised crossover design to investigate the performance effects, and underlying mechanisms, of two volume controlled one-week tapers, of differing intensities, on maximal strength in strength-trained males. A crossover design was selected for this study (and within Chapter Five) to maximise statistical power given a limited participant pool, as well as to allow for comparisons between various time points and between each condition. Specifically, following four weeks of standardised strength training, participants were assigned, at random, to a taper that either increased the intensity of training by 5% (Taper A) or decreased it by 10% (Taper B). In both cases, total training volume decreased by 70%. Participants then had one week of self-directed training, prior to performing another four weeks of standardised strength training followed by the remaining taper. Each four-week block of training ensured that participants were under a similar training load, both individually and collectively, prior to each taper.

Prior to any testing participants were familiarised with testing procedures; familiarisation occurred at least 48-hours prior to any testing. For all testing sessions, participants arrived fasted (water could be consumed ad-libitum prior to sessions), at the same time in the morning ( $\pm 30$  min). Testing occurred prior to each four-week training period (T1), 36-60 hours after the final training session of the four week period (T2), and 36-60 hours after their final taper training session (T3). The time between final training sessions and testing times was kept consistent for each participant. For example, if a participant was tested 36 hours following training in Condition A (i.e. trained late afternoon on Thursday, had one full day's rest Friday, tested on Saturday morning) this was kept consistent for Condition B. In order to identify potential physiological and psychological changes underlying performance effects, participants began each testing session having saliva and finger prick blood samples collected and participants completed a DALDA questionnaire. After these resting measures were completed, participants performed maximal power (CMJ) and strength testing (MTP and IBP) on a force plate; EMG was measured during MTP and IBP. The aim of these

tests was to determine performance and neurological changes as a result of the training and subsequent taper.

The study was approved by the Auckland University of Technology Human Ethics Committee prior to the commencement of the study. All participants were informed of the risks and benefits, and allowed to ask any questions about the research, prior to the provision of written informed consent.

## **Subjects**

The inclusion criteria for the study were: (i) a current deadlift 1RM of at least 1.5 times BW, and, (ii) two or more years of involvement in resistance training. Twelve males met the criteria and volunteered to participate, however one participant did not complete the study. Eleven participants completed the study (age =  $21.3 \pm 3.3$  years, BW =  $92.3 \pm 17.6$  kg, height =  $1.82 \pm 0.08$  m, relative 1RM deadlift  $1.90 \pm 0.20$  times BW).

## **Testing Procedures**

*Strength Testing.* In order to establish training loads, participants performed 1RM testing, according to National Strength & Conditioning Association (NSCA) guidelines (61) for the three powerlifts (squat, bench press and deadlift) within one week of the first testing session. Additionally, participants were also tested for a 2-8RM on all other programmed lifts. 1RM was estimated from these results using the following formula:

$$1RM = \text{Load} / (1.0278 - 0.0278 * \text{Repetitions Performed}) \quad (24)$$

Strength testing was repeated during the week between conditions. All strength testing was performed at the same time of day ( $\pm$  one hour).

*Resting Measures.* Upon arrival at the lab participants were weighed and then consumed 250mL of water. Participants were then seated for five minutes before providing 2mL of saliva by passively drooling into a 10mL polypropylene tube (LabServ, Thermo fisher, New Zealand). This sample was immediately separated into two polypropylene micro-centrifuge tubes (LabServ, Thermo fisher, New Zealand) and

stored on ice. Immediately following trials, samples were relocated into a -80°C freezer, where they remained until analysis. Samples were analyzed in duplicate according to manufacturer's instructions using an enzyme-linked immunosorbent assay (ELISA; DRG International, USA). CV of duplicate ELISA samples was 3.9% for testosterone and 8.5% for cortisol.

A capillary blood sample was then taken from the finger using aseptic technique. Creatine kinase (CK) activity was analyzed from this sample using a Reflotron® systems spectrophotometer (Roche Diagnostics, Switzerland). The typical CV for this device is 3.5% and this method has been used previously as an indicator of muscle damage (83).

The DALDA questionnaire was then completed by participants (as well as prior to each training session as part of the training records kept by participants). The frequency of 'worse than normal' results at each testing session was recorded and analysed to determine any changes across testing sessions. This questionnaire has been used previously to monitor athletes (136, 156) (Chapter Five).

*Performance and Neuromuscular Measures.* Following resting measures and prior to a five minute warm up, performed at 70W on a cycle ergometer, EMG electrodes (Blue Sensor, Medicostest, Rugmarken, Denmark) were placed on the VL and TB according to the SENIAM recommendations by Hermens et al. (74). EMG was measured using a sampling rate of 1000Hz using a PowerLab data acquisition system and analysed in Chart for Windows (ADInstruments, Australia). Normalisation contractions for EMG were performed for VL and TB. Normalisation for TB involved maximal effort elbow extension while standing with the right elbow at 90°, for VL this occurred via maximal knee extension while seated with the right knee at 90°. Three maximal five-second efforts occurred for each muscle group, separated by at least 30-seconds of rest. The force produced during these maximal contractions was measured using a load cell (Sensortronics, CA, USA). Average, rectified EMG was sampled from a 1000ms window centered on peak force; this value was recorded and used for subsequent normalization. The highest average EMG value obtained during MTP and IBP efforts for the VL and TB, respectively, was then compared with this value to normalize EMG.

Studies have shown that the VL activation is similar to that of some of the hamstring muscles throughout the entire deadlift movement, additionally it is also easily accessible and therefore an appropriate muscle to measure muscle activation during the MTP (42, 43). As the TB is one of the agonist muscles during the bench press, particularly at maximal intensities, it was deemed a suitable muscle to use to measure muscle activation during the IBP (95).

Following EMG normalization contractions, participants performed CMJ's on a force plate. Three initial jumps were performed at increasing intensities (~50%, 75% and 100%), followed by three maximal CMJ's which were recorded. The force plate (400 series, Fitness Technology, Australia) recorded at 600Hz during all performance tests. Participants' hands remained on their hips throughout the entire effort on all jumps. The three maximal CMJ's were separated by at least one-minute rest. Jumps were analyzed using the Ballistic Measurement Systems software (BMS, Innervations, Australia) to determine jump height and flight-time: contraction-time. The results were recorded for the highest of the three jumps during each testing session. CV's were 3.0% for jump height and 7.0% for flight-time: contraction-time.

Participants then performed a MTP on the same force plate, with an upright torso and the knee angle at 130° (105). Three initial MTP's were performed at increasing intensities (~50%, 75% and 100%), followed by three maximal recorded MTP's. These MTP's were of approximately five-second duration and separated by approximately one-minute of rest. Participants were told to pull as hard and fast as possible during the MTP. Each maximal MTP effort was analyzed using the BMS software to determine peak force and maximum rate of force development (mRFD), the results were recorded for the MTP with the greatest peak force during each testing session. Peak force was the greatest force output recorded during the contraction, while mRFD was the greatest value obtained for change in force over time. MTP's have previously shown strong correlations to dynamic 1RM performance (105, 106). CV's were 3.3% for MTP peak force and 20.2% MTP mRFD. Due to this large CV, MTP mRFD was excluded from further analysis.

The final test performed was the IBP. This was measured on the same force plate, with the head end of the bench press centered over the force plate, the elbows at 90° and hands no more than 81 cm apart (90). Three initial IBP's were performed at increasing intensities (~50%, 75% and 100%), followed by three maximal recorded IBP's. These IBP's were of approximately five-second duration and separated by approximately one-minute of rest. Participants were told to push as hard and fast as possible during the IBP. Each maximal IBP effort was analyzed using the BMS software to determine peak force and mRFD, the results were recorded for the MTP with the greatest peak force during each testing session. CV's were 3.9% for IBP peak force and 21.3% IBP mRFD (see *Appendix C*). Due to this large CV, IBP mRFD was excluded from further analysis.

### **Training Protocol**

After the first testing session, participants commenced their training programme, focused on improvement in the powerlifts (squat, bench press and deadlift). The objective of this four-week programme was to bring all participants to a similar level of training and fatigue prior to the taper week. This four week programme has been used previously to successfully enhance 1RM performance of the powerlifts (123). The programme involved four exercises per day; beginning with a powerlifting competition lift, then two further competition – or variation thereof – lifts, finishing with a hypertrophy focused accessory lift. Participants were instructed to separate each of the three training days with at least one full rest day between, i.e. if a strength training day occurred on Tuesday, the next strength training day would be Thursday. Participants could continue aerobic or conditioning focused training, but no further resistance training was allowed. If they performed any aerobic or conditioning training, they were instructed to keep this training at their habitual amount.

The tapering training protocol was designed to alter training volume and intensities compared to week four of the training period. Training volume was determined as the load used multiplied by the sets and repetitions performed, total training volume was the sum for exercises performed. Average training intensity was determined as the average percentage of 1RM used per repetition performed, across all exercises. Taper

A had a volume decrease of  $71.9 \pm 1.2\%$  and an increase in intensity of 5.9%, while Taper B had a volume decrease of  $70.0 \pm 1.0\%$  and a decrease in intensity of 8.5%. To balance volume reductions, intensity changes were slightly different from the targeted +5% and -10% targets. Intensity changes have no SD as they were all identical between participants, while weights for differing exercises changed from subject to subject, producing small variations seen in volume. During the taper, accessory lifts were removed and only competition lifts, or variations, remained. This was to ensure specificity to a powerlifting style taper (126) (Chapter Four). Table 6.1 shows the entire four-week training period and Table 6.2 the two tapering protocols. Overall, training compliance was 98.6% for the entire training and tapering periods, with no missed sessions during week four of training or the taper week.

**Table 6.1:** Training programme

Day	Exercise	Week One			Week Two			Week Three			Week Four		
		Reps	Sets	Intensity	Reps	Sets	Intensity	Reps	Sets	Intensity	Reps	Sets	Intensity
1	Bench Press	4	3	80%	4	3	82.5%	3	4	85%	3	4	87.5%
1	Back Squat	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
1	Military Press	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
1	Barbell Row	10	3	70%	10	3	72.5%	8	4	75%	8	4	77.5%
2	Deadlift	4	3	80%	4	3	82.5%	3	4	85%	3	4	87.5%
2	Close Grip Bench Press	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
2	Deficit Deadlift	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
2	Good Morning	10	3	70%	10	3	72.5%	8	4	75%	8	4	77.5%
3	Back Squat	4	3	80%	4	3	82.5%	3	4	85%	3	4	87.5%
3	Paused Bench Press	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
3	Front Squat	6	4	75%	6	4	77.5%	4	4	80%	4	4	82.5%
3	Barbell Row	10	3	70%	10	3	72.5%	8	4	75%	8	4	77.5%

**Table 6.2:** Taper programmes

Day	Exercise	Taper Week A			Taper Week B		
		Reps	Sets	Intensity	Reps	Sets	Intensity
1	Bench Press	4	2	90%	3	3	80%
1	Back Squat	3	3	82.5%	3	4	70%
2	Deadlift	4	2	90%	3	3	80%
2	Close Grip Bench Press	3	3	82.5%	3	4	70%
3	Back Squat	4	2	90%	3	3	80%
3	Paused Bench Press	3	3	82.5%	3	4	70%

*N.B. Intensity is percentage of 1RM; Deficit Deadlift was with feet raised on a 2" plate; Paused Bench Press had a two second pause on the chest.*

## Statistical Analysis

Performance (CMJ height, CMJ flight time: contraction time, MTP and IBP peak force), psychological (DALDA 'worse than') and neuromuscular (normalised EMG) measures were analysed for statistical differences with a two-way repeated measures ANOVA. This method of statistical analysis allowed for differences to be tested for over time, between taper conditions and time by taper interaction. Where a significant difference was found, a Student-Newman-Keuls post-hoc paired comparison was used. Significance was defined as  $P \leq 0.05$ . The above analysis occurred using computer software (Sigma Plot 11.0, Systat Software, Inc., Chicago, Illinois, USA).

ES for performance data were calculated between time points (with data from both tapers pooled together), and between time points for each taper condition. ES were interpreted as: trivial 0-0.2, small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0 and very large  $>2.0$  (81). ES were calculated using computer software (Microsoft Excel, Microsoft Corporation, Redmond, Washington, USA).

## 6.3 Results

CMJ height showed significant improvements over time ( $P < 0.001$ ), with significant increases from T1 to T2 ( $P = 0.010$ ; pooled ES = 0.23), T1 to T3 ( $P = 0.001$ ; pooled ES = 0.37) as well as from T2 to T3 ( $P = 0.002$ ; pooled ES = 0.14). CMJ flight time: contraction time showed significant improvements over time ( $P = 0.004$ ), with significant increases from T1 to T2 ( $P = 0.012$ ; pooled ES = 0.27), and improvements approached significance from T1 to T3 ( $P = 0.073$ ; pooled ES = 0.26). No significant differences were found between taper conditions, or time by taper condition, for any CMJ measure.

MTP relative peak force showed significant improvements over time ( $P = 0.033$ ), with significant increases found from T1 to T2 ( $P = 0.013$ ; pooled ES = 0.25). No significant

differences were found between taper conditions, or time by taper condition, for any MTP or IBP strength measure.

The higher intensity taper produced small ES improvements following the taper for CMJ height (ES = 0.43), CMJ flight time: contraction time (ES = 0.42) and MTP relative peak force (ES = 0.37). In contrast, the lower intensity taper only produced a small ES improvement for CMJ height (ES = 0.30). Table 6.3 shows the results for all performance measures.

**Table 6.3.** Performance results

(A = +5% Intensity Taper; B = -10% Intensity Taper; Numbers indicate testing time point, 1 = Pre-training; 2 = Post-training, 3 = Post-taper). \* represents a small ES improvement compared to that conditions baseline.

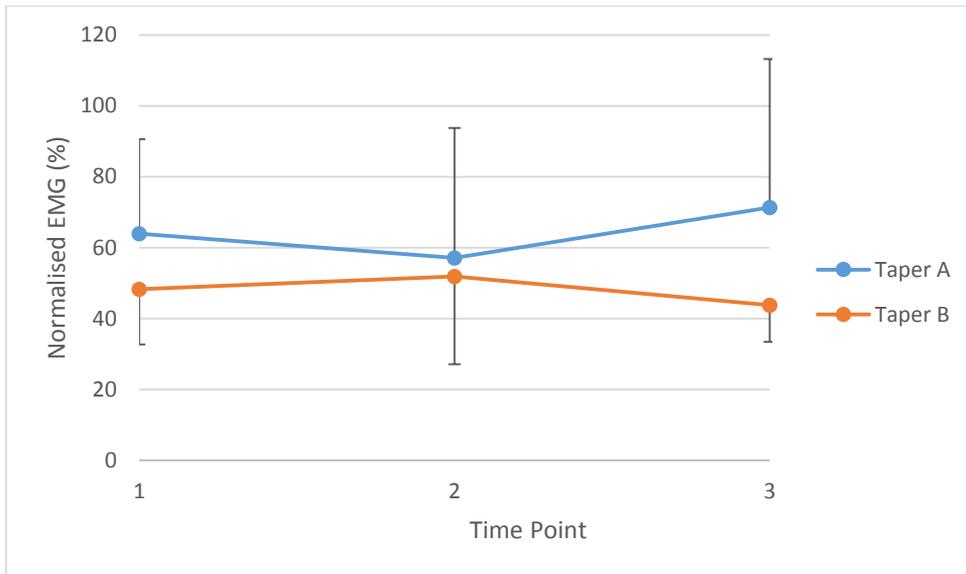
Performance Measures				
	CMJ Height (cm)	CMJ FT: CT	MTP Relative Peak Force (N/kg)	IBP Relative Peak Force (N/kg)
<b>A1</b>	37.8 ± 5.3	0.738 ± 0.171	34.0 ± 4.8	18.6 ± 2.2
<b>A2</b>	39.4 ± 5.7*	0.788 ± 0.163*	35.9 ± 5.0*	18.4 ± 3.0
<b>A3</b>	40.2 ± 5.7*	0.803 ± 0.138*	35.9 ± 5.5*	18.4 ± 2.6
<b>B1</b>	38.2 ± 5.9	0.755 ± 0.160	35.4 ± 5.4	18.8 ± 2.9
<b>B2</b>	39.2 ± 5.2	0.793 ± 0.172*	35.9 ± 4.8	18.6 ± 2.8
<b>B3</b>	39.9 ± 5.3*	0.771 ± 0.169	35.2 ± 5.0	19.1 ± 2.6

There were no significant changes for any hormonal, biochemical or EMG results (Table 6.4 and Figures 6.1 and 6.2).

**Table 6.4:** Hormonal and biochemical results

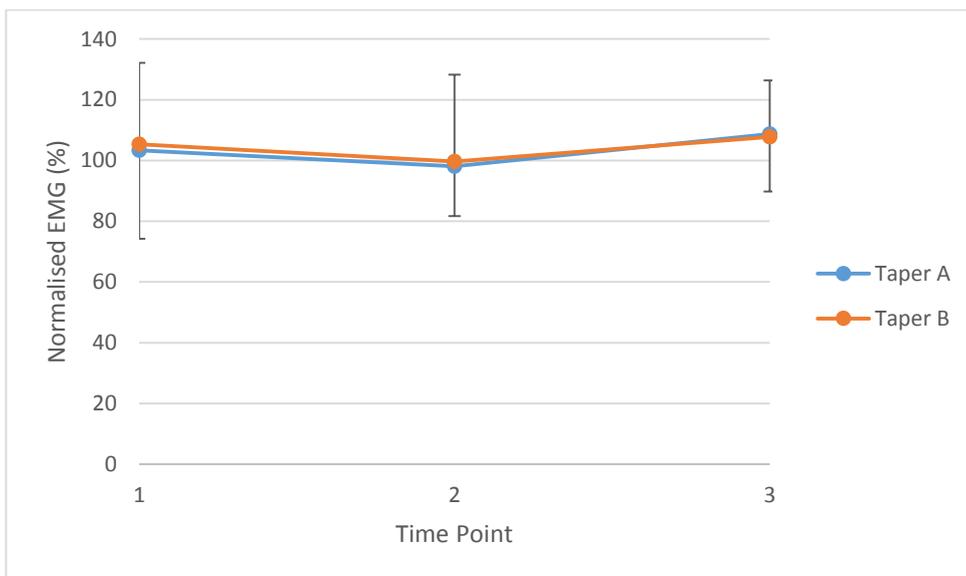
(A = +5% Intensity Taper; B = -10% Intensity Taper; Numbers indicate testing time point, 1 = Pre-training; 2 = Post-training, 3 = Post-taper)

Hormonal and Biochemical Measures			
	Cortisol (ng/ml)	Testosterone (pg/ml)	Creatine Kinase (I/U)
<b>A1</b>	7.65 ± 2.90	150.77 ± 46.43	296.4 ± 216.6
<b>A2</b>	8.89 ± 4.74	155.70 ± 45.92	220.8 ± 101.6
<b>A3</b>	8.62 ± 3.79	151.47 ± 41.31	246.7 ± 136.6
<b>B1</b>	9.20 ± 6.72	156.72 ± 55.00	282.5 ± 155.6
<b>B2</b>	8.94 ± 4.29	146.87 ± 35.57	319.5 ± 204.9
<b>B3</b>	8.04 ± 5.19	138.16 ± 33.27	223.4 ± 162.6



**Figure 6.1:** Normalised Vastus Lateralis EMG over time

Numbers represent testing times, 1 = Pre-training; 2 = Post-training, 3 = Post-taper; Taper A = Intensity +5%, Taper B = Intensity -10%.



**Figure 6.2:** Normalised Triceps Brachii EMG over time

Numbers represent testing times, 1 = Pre-training; 2 = Post-training, 3 = Post-taper; Taper A = Intensity +5%, Taper B = Intensity -10%.

## 6.4 Discussion

The results indicate that a one-week strength taper with a 70% reduction in volume was able to maintain isometric strength while enhancing performance in a CMJ. Significant improvements were observed in CMJ height, CMJ flight time: contraction

time, and MTP relative peak force from pre- to post-training. CMJ height also significantly improved from pre-training to post-taper, and from post-training to post-taper. There was no significant difference in any isometric strength measure from post-training to post-taper. However, the higher intensity taper resulted in small ES improvements post taper vs baseline for MTP relative peak force, CMJ height and CMJ flight time: contraction time, while a decreased intensity taper only showed an improvement in CMJ height.

Improved CMJ height demonstrates the effectiveness of both tapers in enhancing maximal power performance. Maximal power is vital to performance in many sports (35), hence a volume focused strength taper with small changes in intensity could be implemented as an effective tapering strategy to optimise power. Improved CMJ height also provides an indication of more efficient neuromuscular function or a reduced degree of neuromuscular fatigue (169). This performance improvement following a peak utilising training cessation was previously observed in Chapter Five (125), an indication that both styles of taper were effective in reducing fatigue.

There was a tendency for the higher intensity taper to improve performance more than the lower intensity taper. Both tapers resulted in small ES improvements in CMJ height (T3 vs T1), but only the higher intensity taper resulted in small ES improvements in MTP relative peak force (T3 vs T1). Although these changes are small, it is important to note that powerlifting competitors only show very small improvements between major competitions, with CV's of 2-3% across lifts (see Appendix D). Therefore small changes in performance of these lifts may be meaningful to strength athletes. While not controlling training volume, Zaras et al. (184) also showed a tendency for greater improvements in maximal strength – leg press 1RM and isometric peak force – following a heavy load taper (85% 1RM) compared to a light load (30% 1RM) taper. Taken together these results suggest that a higher training intensity may be more beneficial during a taper, when volume is also reduced.

The present results show the importance of volume reductions as a successful tapering strategy. In Chapter Four, it was shown that elite powerlifters usually reduce training volume, by  $58.9 \pm 8.4\%$ , with intensity peaking  $1.9 \pm 0.8$  weeks before a meet, during a

2.4 ± 0.9 week taper (126). Grgic and Mikulic (60) showed that Croatian national powerlifting champions will reduce training volume, by 50.5 ± 11.7%, with intensity peaking 8 ± 3 days before the meet, during an 18 ± 8 day taper. A clear emphasis in both studies was found on dramatically reducing the training volume, while intensity alterations are less clear with more variation amongst athletes (based on standard deviation, SD, of final training sessions). In its most extreme form, a reduction of training volume results in training cessation. Complete training cessation has been shown to be beneficial for maximal strength performance when undertaken for short periods of time (up to a week) in several studies (125, 173, 174). Both Chapter Four (126) and Grgic and Mikulic (60) noted that powerlifters take training cessations of 3.7 ± 1.6 days and 3 ± 1 days, respectively, to finish the taper. These results again emphasise that short term training cessation (or complete volume reduction) is an important part of the taper.

While there were no significant improvements in isometric strength following the taper, maintenance did occur and small ES improvements were found. In previous taper studies, improvements in power performance have often also occurred in conjunction with improved performance in dynamic strength tasks. Coutts et al. (36) showed increases in vertical jump performance following a tapering period as well as improvements in 3RM squat and bench press, and measures of quadriceps and hamstring isokinetic strength in team sport (rugby league) athletes. Zaras (184) found larger improvements in both squat jump power and percentage change in leg press 1RM for a heavy taper in comparison to the light taper in throwers. Marrier et al. (100) showed large improvements in sprint times (qualitative difference *almost certain large decrease*) while the MTP strength improvements were smaller and less certain (qualitative difference *very likely small increase*). However, this is not always the case. Izquierdo et al. (85) showed increases in 1RM half squat and bench press following a taper, while half squat and bench press power (at 60% 1RM) was only maintained in active men. It could be hypothesised, that given the maintenance of isometric strength alongside improved dynamic power, the present taper may be able to improve dynamic strength. However, as dynamic strength was not measured, future research needs to investigate this possibility.

No significant changes were found in neural, hormonal or biochemical measures. Chronic changes in hormones such as testosterone and cortisol are not frequently observed (92). Given that the training volume within the present study was not excessive, it was unlikely changes associated with overreaching would occur (36, 50). However, further investigations could attempt to induce overreaching prior to a strength taper, and observe subsequent performance effects and changes to hormonal and biochemical measures. It is also recommended that, given large variation between individuals in these measures, a larger sample size could be warranted to increase the likelihood of detecting smaller changes.

A limitation of the study, as indicated earlier, was the absence of a dynamic strength measure. While the MTP has been shown to be strongly correlated with performance in dynamic strength tasks such as the squat and the power clean (105), it is not specific to the dynamic strength training undertaken. It should be made clear that isometric strength measures were chosen to detect small changes, they are reproducible and induce minimal fatigue from each effort, whereas 1RM testing may elicit more fatigue and smaller changes can be harder to detect (160). Previous research has shown improvements in 1RM performance from the training protocol used (123) (Appendix B), and within the current study 1RM strength in the powerlifts improved by an average of 7.3% from pre-intervention to between training periods. A dynamic strength test on each testing day may have been useful, and it is recommended future studies utilise some form of dynamic maximal strength testing such as 1RM or velocity at a percentage of 1RM.

## **6.5 Conclusions**

The present study is consistent with previous literature (36, 56, 63, 85, 100), that a strength taper with volume reductions can have positive effects on maximal strength and power performance. There was also a tendency for increased intensity to produce more favourable performance improvements, although no significant differences were found between conditions. Enhanced vertical jump performance may also indicate a reduction in neuromuscular fatigue for both tapers. It is recommended that athletes

tapering for maximal strength performance make significant reductions in training volume, while making smaller alterations (if any) to intensity.

## CHAPTER SEVEN

### GENERAL DISCUSSION AND PRACTICAL APPLICATIONS

The major aim of this thesis was to determine how strength-trained men can best structure their taper to improve strength performance, and the mechanisms underlying the performance improvements. This chapter draws the thesis together by summarising the major findings, linking chapters together, and provides some practical applications of the findings. Limitations of the research are identified, and finally, future research directions are proposed.

#### 7.1 Summary

The first literature review (Chapter Two) provided valuable information regarding effective strength training strategies. This literature review indicated that strength-trained individuals should train at high intensities (>80% 1RM), for multiple sets, at least twice per week per muscle group, with a periodised approach (93, 121, 130, 133). These findings were utilised directly in the design of the initial training period for both training studies (Chapters Five and Six), to ensure an effective training stimulus was applied.

In the second literature review (Chapter Three), studies related to tapering for maximal strength were reviewed. These studies, although limited in number, revealed that both step and progressive tapers, with reductions in training volume (30-70%) and maintained or slightly increased intensity were most effective at enhancing maximal strength (56, 184). However, few studies had directly compared the effectiveness of differing magnitudes of change within these variables. The literature also demonstrated the effectiveness of short periods of complete training cessation for strength maintenance (less than one week) or potential improvement (two to four days) (173, 174). Performance improvements may be attributed to muscle recovery/repair, an enhanced anabolic environment or perhaps enhanced neuromuscular function (63, 85). Gaps identified within this literature review led to the design of two cross-over training studies; one

investigating the effects of short-term training cessations on strength (Chapter Five), the other investigating the effects of differing training intensities during a strength taper (Chapter Six).

The tapering practices of New Zealand's elite powerlifters were qualitatively analysed using semi-structured interviews to determine what practices strength athletes currently undertake during a taper (Chapter Four). This study found that many of the practices shown to be effective in the literature (Chapter Three) are currently utilised by strength athletes. These athletes reduced training volume (by  $58.9 \pm 8.4\%$ ), while maintaining (or slightly reducing) training intensity. The taper lasted  $2.4 \pm 0.9$  weeks, with the final resistance training session  $3.7 \pm 1.6$  days out from competition. Tapering was performed to achieve maximal recovery, and practices were largely informed through trial and error, with changes based upon 'feel'. Another interesting finding was that during the taper athletes tend to remove accessory exercises and focus primarily upon the competition lifts. These findings assisted in planning the large volume reductions and competition lift focus during the tapering training study (Chapter Six), as well as provide a duration of training cessation for comparison (Chapter Five).

Chapter Three identified that limited studies had investigated optimal durations of training cessation or the mechanisms behind their effectiveness. Hence, the first training study investigated the effects of two differing lengths of training cessation on maximal strength (Chapter Five). Participants performed four weeks of strength training followed by 3.5 or 5.5 days of training cessation, in a crossover design. Statistically significant performance improvements, compared to pre-training, were observed for both CMJ height and IBP relative peak force following short term training cessation ( $P = 0.022$  and  $P = 0.011$ , respectively, both  $ES = 0.30$ ) when groups were combined. As this significant improvement was not present on the final training day, it shows that short-term training cessation was an effective means of enhancing strength. However, no duration was more effective. These results suggest that a short period of strength training cessation (less than one week) can have positive effects on maximal strength expression in strength trained men, perhaps due to decreased neuromuscular fatigue.

Comparisons of differing taper strategies had been identified as an under researched area, particularly in strength trained individuals (Chapter Three). Thus, Chapter Six utilised a crossover design to investigate two tapers involving different changes in intensity in strength trained men. Following four weeks of training participants increased (+5%) or decreased (-10%) training intensity during a one-week volume reduced (-70%) taper. Statistically significant improvements were found in CMJ height across all time points when group data was combined (T1 to T2  $P = 0.010$ ,  $ES = 0.23$ ; T1 to T3  $P = 0.001$ ,  $ES = 0.37$ ; and, T2 to T3  $P = 0.002$ ,  $ES = 0.14$ ). CMJ flight time: contraction time also showed significant improvements over time, with significant improvements from pre-to post training ( $P = 0.012$ ,  $ES = 0.27$ ). MTP relative peak force showed significant improvements over time, with significant increases found from pre-to post training ( $P = 0.013$ ,  $ES = 0.25$ ). No significant differences were found between groups for any measure. However, the higher intensity taper produced small ES improvements following the taper for CMJ height ( $ES = 0.43$ ), CMJ flight time: contraction time ( $ES = 0.42$ ) and MTP relative peak force ( $ES = 0.37$ ). In contrast, the lower intensity taper only produced a small improvement for CMJ height ( $ES = 0.30$ ). Enhanced vertical jump performance may indicate a reduction in neuromuscular fatigue for both conditions following the taper. These results indicate that a strength taper with volume reductions can have positive effects on maximal strength and power performance in strength trained men, with a tendency for higher intensity to produce greater performance improvements.

## **7.2 Practical Applications**

The findings within this thesis can offer some useful recommendations for strength and conditioning coaches, strength athletes and sport scientists:

- Strength-trained athletes should take a minimum of two days (48 hours), but not more than a week, off strength training prior to an important event with around four days appearing to be optimal for peaking.

- Brief periods with no strength training (less than a week) could be confidently implemented as planned recovery during a training cycle, or when an athlete may be unable to access appropriate facilities (e.g. travel). However, longer periods of training cessation (greater than one week) should be avoided as extended durations away from strength training may impair maximal strength.
- Athletes should be cautious about going too heavy too often (over exertion or frequently testing strength) prior to important events as this may impair competitive performance.
- Training diaries, or a method of recording training, should be utilised to determine changes in training load over the course of a training cycle. In addition to exercises, sets, repetitions and loads, simple wellness and stress measures like those collected within the questionnaires in this thesis (mood, diet, sleep, muscle pain etc.) may provide useful information for athletes and practitioners. This data can be used as the basis of reflective practice to help competitors optimize their individual tapering practices, continuing to implement effective strategies, while avoiding those that were ineffective. These measures may also assist practitioners with making adjustments to programming.
- During a taper, non-specific strength training exercises should be removed and the focus remain primarily on sport specific strength training exercises. For example, accessory exercises which focus on training musculature rather than movements (e.g. dumbbell curls, leg extensions) add stress but do not train specific movements, while multipoint compound exercises generally train both muscles and motor patterns (e.g. squats, pulls). Given there will be considerably lower training volume during a taper, the more specific exercises are of higher value and thus should be prioritised during the taper.

- When tapering for maximal strength the focus should be on substantial reductions in training volume, while making smaller alterations (if any) to intensity. Total training volume can be reduced by lowering the volume of individual training sessions while maintaining training frequency, or alternatively through reducing the number of sessions within a given training week while maintaining the volume of individual sessions.
- Prior training of athletes needs to be considered when planning tapering periods. If greater fatigue has been accumulated then greater reductions in training load, or a longer taper period, may be required.

### **7.3 Limitations**

The following limitations of the studies within the thesis are acknowledged:

- Chapter Four:
  - Elite powerlifters were all recruited from one nation, New Zealand, therefore the findings may not reflect practices from other nations.
  - The status of 'elite' was based upon the NZPF standards from 2014. These were updated in 2017.
  - Only powerlifters were involved within this study, findings are specific to this pure strength sport and should be interpreted within this context when applied to other sports.
- Chapters Five and Six:
  - Strength-trained participants were utilised within the training studies, however, these were not competitive strength athletes.
  - Participant numbers were limited, primarily due to a limited recruitment pool in the local community.
  - The period between each training block was limited and thus some carryover effect may have occurred. Some control of this occurred through the attempt to counter-balance the order of conditions. This was achieved in Chapter Five, but was slightly uneven in Chapter Six due to participant drop out.

- The training duration prior to each intervention was only a four-week period, this may not reflect an athlete's typical training cycle.
- There was no control over aerobic or anaerobic training performed, however participants were instructed to keep this consistent throughout the training periods.
- Strength was measured solely with the use of MTP and IBP, not with specific dynamic measures, such as 1RM.
- Only male athletes were recruited for these training studies.

#### **7.4 Future Research Directions**

The thesis has provided insights into effective methods of tapering (and peaking) to enhance performance in maximal strength tasks. These results have provided practical applications which can be utilised by coaches and athletes. However, there are several key areas in which future research should occur:

- Further studies should investigate the current tapering practices of powerlifters from other nations, as well as strength athletes in other sports such as Strongman and Olympic Weightlifting. This will help to extend upon the findings of Chapter Three. Interestingly this is occurring, with a recent publication that investigated tapering practices of Croatian powerlifters (60).
- In Chapter Three, 90.9% of the elite powerlifters interviewed stated that the deadlift took longer to recover from than other exercises. This claim warrants further investigation. Studies investigating the fatigue, through peripheral and central factors, caused from heavy deadlift training sessions, in comparison to other strength exercises (such as the squat and bench press), would provide useful insights. A recent study by Barnes et al. (12) compared the acute responses to squats and deadlifts performed at 95% 1RM in strength trained men and found no significant differences in fatigue. However further work in this area is warranted.

- Several powerlifters commented on the negative effects of weight cutting practices on their performance in this thesis (Chapter Four). Weight cutting is a common practice in strength sports as competitions often occur in weight restricted categories. Information regarding such practices exists in other sports, such as rowing and wrestling (102, 145, 147, 148), but the effects of weight cutting on pure strength sports, such as powerlifting, requires further investigation. Given its occurrence during the tapering period any negative impacts could have a significant influence on performance, therefore studies should investigate the effects of weight loss (and subsequent rehydration) on maximal strength in strength-trained athletes.
- Chapters Five and Six utilised a force plate to test strength changes following training cessation and a strength taper. It is recommended that future studies also utilise some form of dynamic strength measure, such as a 1RM specific to training undertaken, when testing tapering strategies. This would provide information in a sport specific context.
- As the focus of Chapter Six was the effects of training intensity during a strength taper, the effects of variations in training volume during a strength taper requires investigation. Specifically, higher and lower volume reductions should be investigated, utilising strength-trained participants.
- The method through which athletes lower training volume also requires investigation. Studies should look to determine whether differences exist through reducing volume with reduced training frequency in comparison to reduced session volume. In Chapter Four it was revealed that elite powerlifters tend to reduce their training frequency during a taper and thus this strategy of volume reduction warrants further investigation.
- Chapter Six utilised a step taper. Further research should compare different types of strength tapers in strength-trained participants to determine whether progressive tapering strategies may be more effective. Such

investigations should attempt to control for total reductions in training load over the length of the tapering period.

- Chapters Five and Six saw no significant changes to hormonal or biochemical measures. Future research could look to implement a period of overreaching prior to the taper to investigate potential hormonal and biochemical changes during tapering. Greater numbers of participants within studies may also increase the likelihood of detecting changes within these variables.
- All the studies were conducted using men. Future research should be undertaken to investigate the effectiveness of tapering strategies in female strength athletes.

## REFERENCES

1. Progression Models in Resistance Training for Healthy Adults. *Medicine & Science in Sports & Exercise* 41: 687-708, 2009.
2. Aagaard P, Andersen JL, Dyhre-Poulsen P, Leffers A-M, Wagner A, Magnusson SP, Halkjær-Kristensen J, and Simonsen EB. A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. *The Journal of Physiology* 534: 613-623, 2001.
3. Amirthalingam T, Mavros Y, Wilson GC, Clarke JL, Mitchell L, and Hackett DA. Effects of a modified german volume training program on muscular hypertrophy and strength. *Journal of Strength & Conditioning Research* [Epub ahead of print], 2016.
4. Andersen JL and Aagaard P. Myosin heavy chain IIX overshoot in human skeletal muscle. *Muscle & Nerve* 23: 1095-1104, 2000.
5. Anderson T and Cattanach D. Effects of three different rest periods on expression of developed strength. *Journal of Strength & Conditioning Research* 7: 185, 1993.
6. Anderson T and Kearney JT. Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Research Quarterly for Exercise and Sport* 53: 1-7, 1982.
7. Arazi H and Asadi A. Effects of 8 weeks equal-volume resistance training with different workout frequency on maximal strength, endurance and body composition. *International Journal of Sports Science and Engineering* 5: 112-111, 2011.
8. Aubry A, Hauswirth C, Louis J, Coutts AJ, and Le Meur Y. Functional overreaching: The key to peak performance during the taper? *Medicine & Science in Sports & Exercise*, 2014.
9. Baker D. Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. *Journal of Strength & Conditioning Research* 16: 581-585, 2002.
10. Baker D, Wilson G, and Carlyon R. Periodization: The effect on strength of manipulating volume and intensity. *Journal of Strength & Conditioning Research* 8: 235-242, 1994.
11. Bamman MM, Shipp JR, Jiang J, Gower BA, Hunter GR, Goodman A, McLafferty CL, and Urban RJ. Mechanical load increases muscle IGF-I and androgen receptor mRNA concentrations in humans. *American Journal of Physiology - Endocrinology and Metabolism* 280: E383-E390, 2001.
12. Barnes MJ, Miller A, Reeve D, and Stewart RJ. Acute neuromuscular and endocrine responses to two different compound exercises: Squat versus deadlift. *Journal of Strength & Conditioning Research* [Epub ahead of print], 2017.
13. Bartolomei S, Hoffman JR, Merni F, and Stout JR. A comparison of traditional and block periodized strength training programs in trained athletes. *Journal of Strength & Conditioning Research* 28: 990-997, 2014.
14. Bazzyler CD, Mizuguchi S, Harrison AP, Sato K, Kavanaugh AA, Deweese BH, and Stone MH. Changes in muscle architecture, explosive ability, and track and field throwing performance throughout a competitive season and following a taper. *Journal of Strength & Conditioning Research*, 2016.

15. Bemben MG. Use of diagnostic ultrasound for assessing muscle size. *Journal of Strength & Conditioning Research* 16: 103-108, 2002.
16. Berger R. Effect of varied weight training programs on strength. *Research Quarterly American Association for Health, Physical Education and Recreation* 33: 168-181, 1962.
17. Berger RA. Optimum repetitions for the development of strength. *Research Quarterly American Association for Health, Physical Education and Recreation* 33: 334-338, 1962.
18. Berger RA. Comparative effects of three weight training programs. *Research Quarterly American Association for Health, Physical Education and Recreation* 34: 396-398, 1963.
19. Blazevich AJ, Gill ND, Bronks R, and Newton RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. *Medicine & Science in Sports & Exercise* 35: 2013-2022, 2003.
20. Blazevich AJ, Gill ND, Deans N, and Zhou S. Lack of human muscle architectural adaptation after short-term strength training. *Muscle & Nerve* 35: 78-86, 2007.
21. Bosquet L, Montpetit J, Arvisais D, and Mujika I. Effects of tapering on performance: A meta-analysis. *Medicine & Science in Sports & Exercise* 39: 1358-1365, 2007.
22. Braith R, Graves J, Pollock M, Leggett S, Carpenter D, and Colvin A. Comparison of 2 vs 3 days/week of variable resistance training during 10-and 18-week programs. *International Journal of Sports Medicine* 10: 450-454, 1989.
23. Brännström A, Rova A, and Yu J-G. Effects and mechanisms of tapering in maximizing muscular power. *Sport and Art* 1: 18-23, 2013.
24. Brzycki M. Strength testing—predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance* 64: 88-90, 1993.
25. Campos GE, Luecke TJ, Wendeln HK, Toma K, Hagerman FC, Murray TF, Ragg KE, Ratamess NA, Kraemer WJ, and Staron RS. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *European Journal of Applied Physiology* 88: 50-60, 2002.
26. Candow DG and Burke DG. Effect of short-term equal-volume resistance training with different workout frequency on muscle mass and strength in untrained men and women. *Journal of Strength & Conditioning Research* 21: 204-207, 2007.
27. Chestnut JL and Docherty D. The Effects of 4 and 10 Repetition Maximum Weight-Training Protocols on Neuromuscular Adaptations in Untrained Men. *Journal of Strength & Conditioning Research* 13: 353-359, 1999.
28. Chiu LZ and Barnes JL. The fitness-fatigue model revisited: Implications for planning short-and long-term training. *Strength & Conditioning Journal* 25: 42-51, 2003.
29. Choi J, Takahashi H, Itai Y, and Takamatsu K. The difference between effects of “power-up type” and “bulk-up type” strength training exercises. *Japanese Journal of Physical Fitness and Sports Medicine* 47: 119-129, 1998.
30. Cholewicki J, McGill S, and Norman R. Lumbar spine loads during the lifting of extremely heavy weights. *Medicine & Science in Sports & Exercise* 23: 1179, 1991.
31. Chtourou H, Chaouachi A, Driss T, Dogui M, Behm DG, Chamari K, and Souissi N. The effect of training at the same time of day and tapering period on the

- diurnal variation of short exercise performances. *Journal of Strength & Conditioning Research* 26: 697-708, 2012.
32. Clarkson PM and Hubal MJ. Exercise-induced muscle damage in humans. *American Journal of Physical Medicine & Rehabilitation* 81: S52-S69, 2002.
  33. Colquhoun RJ, Gai CM, Walters J, Brannon AR, Kilpatrick MW, D'agostino DP, and Campbell WI. Comparison of powerlifting performance in trained men using traditional and flexible daily undulating periodization. *Journal of Strength & Conditioning Research* 31: 283-291, 2017.
  34. Cormack SJ, Newton RU, and McGuigan MR. Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance* 3: 359-374, 2008.
  35. Cormie P, McGuigan MR, and Newton RU. Developing maximal neuromuscular power. *Sports Medicine* 41: 17-38, 2011.
  36. Coutts A, Reaburn P, Piva TJ, and Murphy A. Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players. *International Journal of Sports Medicine* 28: 116-124, 2007.
  37. Craig BW and Kang H-Y. Growth hormone release following single versus multiple sets of back squats: Total work versus power. *Journal of Strength & Conditioning Research* 8: 270-275, 1994.
  38. Creswell JW and Miller DL. Determining validity in qualitative inquiry. *Theory Into Practice* 39: 124-130, 2000.
  39. Crewther B, Cronin J, Keogh J, and Cook C. The salivary testosterone and cortisol response to three loading schemes. *Journal of Strength & Conditioning Research* 22: 250-255, 2008.
  40. de Lacey J, Brughelli M, McGuigan M, Hansen K, Samozino P, and Morin J-B. The effects of tapering on power-force-velocity profiling and jump performance in professional rugby league players. *Journal of Strength & Conditioning Research* 28: 3567-3570, 2014.
  41. Deschenes MR, Giles JA, McCoy RW, Volek JS, Gomez AL, and Kraemer WJ. Neural factors account for strength decrements observed after short-term muscle unloading. *American Journal of Physiology -Regulatory, Integrative and Comparative Physiology* 282: R578-R583, 2002.
  42. Ebben W, Feldmann C, Dayne A, Mitsche D, Alexander P, and Knetzger K. Muscle activation during lower body resistance training. *International Journal of Sports Medicine* 30: 1-8, 2009.
  43. Escamilla RF, Francisco AC, Kayes AV, Speer KP, and Moorman 3rd C. An electromyographic analysis of sumo and conventional style deadlifts. *Medicine & Science in Sports & Exercise* 34: 682-688, 2002.
  44. Evans WJ and Lambert CP. Physiological basis of fatigue. *American Journal of Physical Medicine & Rehabilitation* 86: S29-S46, 2007.
  45. Everett G. *Olympic Weightlifting: A Complete Guide for Athletes & Coaches*. United States of America: Catalyst Athletics, 2016.
  46. Federation IP. *Technical Rules Book 2015*. Luxemburg, 2014.
  47. Flanagan EP. The effect size statistic - Applications for the strength and conditioning coach. *Strength & Conditioning Journal* 35: 37-40, 2013.
  48. Fleck SJ. Periodized strength training: a critical review. *Journal of Strength & Conditioning Research* 13: 82-89, 1999.

49. Folland JP and Williams AG. Morphological and neurological contributions to increased strength. *Sports Medicine* 37: 145-168, 2007.
50. Fry AC and Kraemer WJ. Resistance exercise overtraining and overreaching: Neuroendocrine responses. *Sports Medicine* 23: 106-129, 1997.
51. Fry AC, Kraemer WJ, Borselen FV, Lynch JM, Marsit JL, Roy EP, Triplett NT, and Knuttgen HG. Performance decrements with high-intensity resistance exercise overtraining. *Medicine & Science in Sports & Exercise* 26: 1165-1173, 1994.
52. Fry AC, Kraemer WJ, Lynch JM, Triplett NT, and Koziris LP. Does short-term near-maximal intensity machine resistance training induce overtraining? *Journal of Strength & Conditioning Research* 8: 188-191, 1994.
53. Fry AC, Webber JM, Weiss LW, Aeber MP, Vaczi M, and Pattison NA. Muscle fiber characteristics of competitive power lifters. *Journal of Strength & Conditioning Research* 17: 402-410, 2003.
54. Gentil P, Fischer B, Martorelli A, Lima R, and Bottaro M. Effects of equal-volume resistance training performed one or two times a week in upper body muscle size and strength of untrained young men. *The Journal of Sports Medicine and Physical Fitness* 55: 144-149, 2014.
55. Gentil P, Soares SRS, Pereira MC, Cunha RRd, Martorelli SS, Martorelli AS, and Bottaro M. Effect of adding single-joint exercises to a multi-joint exercise resistance-training program on strength and hypertrophy in untrained subjects. *Applied Physiology, Nutrition, and Metabolism* 38: 341-344, 2013.
56. Gibala MJ, MacDougall JD, and Sale DG. The effects of tapering on strength performance in trained athletes. *International Journal of Sports Medicine* 15: 492-497, 1994.
57. González-Badillo JJ, Gorostiaga EM, Arellano R, and Izquierdo M. Moderate resistance training volume produces more favorable strength gains than high or low volumes during a short-term training cycle. *Journal of Strength & Conditioning Research* 19: 689-697, 2005.
58. Gotshalk LA, Loebel CC, Nindl BC, Putukian M, Sebastianelli WJ, Newton RU, Häkkinen K, and Kraemer WJ. Hormonal responses of multiset versus single-set heavy-resistance exercise protocols. *Canadian Journal of Applied Physiology* 22: 244-255, 1997.
59. Graves JE, Pollock ML, Leggett SH, Braith RW, Carpenter DM, and Bishop LE. Effect of reduced training frequency on muscular strength. *International Journal of Sports Medicine* 9: 316-319, 1988.
60. Grgic J and Mikulic P. Tapering practices of Croatian open-class powerlifting champions. *Journal of Strength & Conditioning Research* [Epub ahead of print], 2016.
61. Haff GG and Triplett NT. *Essentials of Strength Training and Conditioning (4th Edition)*. Human Kinetics, 2015.
62. Häkkinen K and Kallinen M. Distribution of strength training volume into one or two daily sessions and neuromuscular adaptations in female athletes. *Electromyography and Clinical Neurophysiology* 34: 117-124, 1994.
63. Häkkinen K, Kallinen M, Komi PV, and Kauhanen H. Neuromuscular adaptations during short-term "normal" and reduced training periods in strength athletes. *Electromyography and Clinical Neurophysiology* 31: 35-42, 1991.
64. Häkkinen K, Komi P, and Tesch P. Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fiber and metabolic

- characteristics of leg extensor muscles. *Scandinavian Journal of Medicine & Science in Sports* 3: 50-58, 1981.
65. Häkkinen K and Komi PV. Electromyographic changes during strength training and detraining. *Medicine & Science in Sports & Exercise* 15: 455-460, 1983.
  66. Häkkinen K, Komi PV, Alen M, and Kauhanen H. EMG, muscle fibre and force production characteristics during a 1 year training period in elite weight-lifters. *European Journal of Applied Physiology and Occupational Physiology* 56: 419-427, 1987.
  67. Häkkinen K, Pakarinen A, Alen M, Kauhanen H, and Komi P. Relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training in elite weight lifters. *International Journal of Sports Medicine* 8: S61-S65, 1987.
  68. Häkkinen K, Pakarinen A, Alen M, Kauhanen H, and Komi P. Neuromuscular and hormonal adaptations in athletes to strength training in two years. *Journal of Applied Physiology* 65: 2406-2412, 1988.
  69. Harries SK, Lubans DR, and Callister R. Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. *Journal of Strength & Conditioning Research* 29: 1113-1125, 2015.
  70. Harris GR, Stone MH, O'Bryant HS, Proulx CM, and Johnson RL. Short-term performance effects of high power, high force, or combined weight-training methods. *Journal of Strength & Conditioning Research* 14: 14-20, 2000.
  71. Hartman MJ, Clark B, Bembem DA, Kilgore JL, and Bembem MG. Comparisons between twice-daily and once-daily training sessions in male weight lifters. *International Journal of Sports Physiology and Performance* 2: 159-169, 2007.
  72. Hartmann H, Wirth K, Keiner M, Mickel C, Sander A, and Szilvas E. Short-term Periodization Models: Effects on Strength and Speed-strength Performance. *Sports Medicine* 45: 1373-1386, 2015.
  73. Hellard P, Avalos M, Hauswirth C, Pyne D, Toussaint JF, and Mujika I. Identifying Optimal Overload and Taper in Elite Swimmers over Time. *Journal of Sports Science & Medicine* 12: 668-678, 2013.
  74. Hermens HJ, Freriks B, Disselhorst-Klug C, and Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology* 10: 361-374, 2000.
  75. Hoff J, Gran A, and Helgerud J. Maximal strength training improves aerobic endurance performance. *Scandinavian Journal of Medicine & Science in Sports* 12: 288-295, 2002.
  76. Hoffman JR, Cooper J, Wendell M, and Kang J. Comparison of Olympic vs. traditional power lifting training programs in football players. *Journal of Strength & Conditioning Research* 18: 129-135, 2004.
  77. Hoffman JR, Kraemer WJ, Fry AC, Deschenes M, and Kemp M. The effects of self-selection for frequency of training in a winter conditioning program for football. *Journal of Strength & Conditioning Research* 4: 76-82, 1990.
  78. Hoffman JR, Ratamess NA, Klatt M, Faigenbaum AD, Ross RE, Tranchina NM, McCurley RC, Kang J, and Kraemer WJ. Comparison between different off-season resistance training programs in Division III American college football players. *Journal of Strength & Conditioning Research* 23: 11-19, 2009.
  79. Hooper SL, Mackinnon LT, and Ginn EM. Effects of three tapering techniques on the performance, forces and psychometric measures of competitive swimmers.

- European Journal of Applied Physiology and Occupational Physiology* 78: 258-263, 1998.
80. Hooper SL, MacKinnon LT, and Hanrahan S. Mood states as an indication of staleness and recovery. *International Journal of Sport Psychology*, 1997.
  81. Hopkins WG. A scale of magnitudes for effect statistics. *A New View of Statistics*, 2002.
  82. Hortobagyi T, Houmard JA, Stevenson JR, Fraser DD, Johns RA, and Israel RG. The effects of detraining on power athletes. *Medicine & Science in Sports & Exercise* 25: 929-935, 1993.
  83. Hughes J, Chapman P, Brown S, Johnson N, and Stannard S. Indirect measures of substrate utilisation following exercise-induced muscle damage. *European Journal of Sport Science* 13: 509-517, 2013.
  84. Issurin VB. Benefits and limitations of block periodized training approaches to athletes' preparation: A review. *Sports Medicine* 46: 329, 2016.
  85. Izquierdo M, Ibanez J, Gonzalez-Badillo JJ, Ratamess NA, Kraemer WJ, Häkkinen K, Bonnabau H, Granados C, French DN, and Gorostiaga EM. Detraining and tapering effects on hormonal responses and strength performance. *Journal of Strength & Conditioning Research* 21: 768-775, 2007.
  86. Jonker L, Elferink-Gemser MT, and Visscher C. Differences in self-regulatory skills among talented athletes: The significance of competitive level and type of sport. *Journal of Sports Sciences* 28: 901-908, 2010.
  87. Kadi F, Bonnerud P, Eriksson A, and Thornell L-E. The expression of androgen receptors in human neck and limb muscles: effects of training and self-administration of androgenic-anabolic steroids. *Histochemistry and Cell Biology* 113: 25-29, 2000.
  88. Kadi F, Schjerling P, Andersen LL, Charifi N, Madsen JL, Christensen LR, and Andersen JL. The effects of heavy resistance training and detraining on satellite cells in human skeletal muscles. *Journal of Physiology* 558: 1005-1012, 2004.
  89. Kawakami Y, Abe T, Kuno S-Y, and Fukunaga T. Training-induced changes in muscle architecture and specific tension. *European Journal of Applied Physiology and Occupational Physiology* 72: 37-43, 1995.
  90. Kilduff LP, Vidakovic P, Cooney G, Twycross-Lewis R, Amuna P, Parker M, Paul L, and Pitsiladis YP. Effects of creatine on isometric bench-press performance in resistance-trained humans. *Medicine & Science in Sports & Exercise* 34: 1176-1183, 2002.
  91. Kraemer WJ, Marchitelli L, Gordon SE, Harman E, Dziados JE, Mello R, Frykman P, McCurry D, and Fleck SJ. Hormonal and growth factor responses to heavy resistance exercise protocols. *Journal of Applied Physiology* 69: 1442-1450, 1990.
  92. Kraemer WJ and Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine* 35: 339-361, 2005.
  93. Krieger JW. Single versus multiple sets of resistance exercise: A meta-regression. *The Journal of Strength & Conditioning Research* 23: 1890-1901, 2009.
  94. Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: A meta-analysis. *The Journal of Strength & Conditioning Research* 24: 1150-1159, 2010.
  95. Król H and Golas A. Effect of barbell weight on the structure of the flat bench press. *Journal of Strength & Conditioning Research* [Epub ahead of print], 2017.

96. Larson Jr GD and Potteiger JA. A comparison of three different rest intervals between multiple squat bouts. *Journal of Strength & Conditioning Research* 11: 115-118, 1997.
97. Le Meur Y, Hausswirth C, and Mujika I. Tapering for competition: A review. *Science & Sports* 27: 77-87, 2012.
98. Linnamo V, Häkkinen K, and Komi P. Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology and Occupational Physiology* 77: 176-181, 1997.
99. Mangine G, Hoffman J, Fukuda D, Stout J, and Ratamess N. Improving muscle strength and size: The importance of training volume, intensity, and status. *Kinesiology* 47: 131-138, 2015.
100. Marrier B, Robineau J, Piscione J, Lacombe M, Peeters A, Hausswirth C, Morin J-B, and Meur YL. Supercompensation kinetics of physical qualities during a taper in team sport athletes. *International Journal of Sports Physiology and Performance* 0: 1-24, 2017.
101. Marshall P, McEwen M, and Robbins D. Strength and neuromuscular adaptation following one, four, and eight sets of high intensity resistance exercise in trained males. *European Journal of Applied Physiology* 111: 3007-3016, 2011.
102. Marttinen RH, Judelson DA, Wiersma LD, and Coburn JW. Effects of self-selected mass loss on performance and mood in collegiate wrestlers. *Journal of Strength & Conditioning Research* 25: 1010-1015, 2011.
103. McBride JM, Triplett-McBride T, Davie A, and Newton RU. A comparison of strength and power characteristics between power lifters, Olympic lifters, and sprinters. *Journal of Strength & Conditioning Research* 13: 58-66, 1999.
104. McGuigan MR and Kane MK. Reliability of performance of elite Olympic weightlifters. *The Journal of Strength & Conditioning Research* 18: 650-653, 2004.
105. McGuigan MR and Winchester JB. The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science & Medicine* 7: 101, 2008.
106. McGuigan MR, Winchester JB, and Erickson T. The importance of isometric maximum strength in college wrestlers. *Journal of Sports Science & Medicine* 5: 108-113, 2006.
107. McLean BD, Coutts AJ, Kelly V, McGuigan MR, and Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance* 5: 367-383, 2010.
108. McLester JR, Bishop E, and Guilliams M. Comparison of 1 day and 3 days per week of equal-volume resistance training in experienced subjects. *Journal of Strength & Conditioning Research* 14: 273-281, 2000.
109. Miranda F, Simão R, Rhea M, Bunker D, Prestes J, Leite RD, Miranda H, de Salles BF, and Novaes J. Effects of linear vs. daily undulatory periodized resistance training on maximal and submaximal strength gains. *Journal of Strength & Conditioning Research* 25: 1824-1830, 2011.
110. Monteiro AG, Aoki MS, Evangelista AL, Alveno DA, Monteiro GA, da Cruz Piçarro I, and Ugrinowitsch C. Nonlinear periodization maximizes strength gains in split resistance training routines. *Journal of Strength & Conditioning Research* 23: 1321-1326, 2009.

111. Mujika I. Intense training: The key to optimal performance before and during the taper. *Scandinavian Journal of Medicine & Science in Sports* 20: 24-31, 2010.
112. Mujika I and Padilla S. Detraining: Loss of training-induced physiological and performance adaptations. Part I. *Sports Medicine* 30: 79-87, 2000.
113. Mujika I and Padilla S. Scientific bases for precompetition tapering strategies. *Medicine and Science in Sports and Exercise* 35: 1182-1187, 2003.
114. Mujika I, Padilla S, and Pyne D. Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. *International Journal of Sports Medicine* 23: 582-587, 2002.
115. Mujika I, Padilla S, Pyne D, and Busso T. Physiological changes associated with the pre-event taper in athletes. *Sports Medicine* 34: 891-927, 2004.
116. Newton RU, Murphy AJ, Humphries BJ, Wilson GJ, Kraemer WJ, and Häkkinen K. Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal of Applied Physiology and Occupational Physiology* 75: 333-342, 1997.
117. O'Shea P. Effects of selected weight training programs on the development of strength and muscle hypertrophy. *Research Quarterly American Association for Health, Physical Education and Recreation* 37: 95-102, 1966.
118. Ostrowski KJ, Wilson GJ, Weatherby R, Murphy PW, and Lyttle AD. The effect of weight training volume on hormonal output and muscular size and function. *Journal of Strength & Conditioning Research* 11: 148-154, 1997.
119. Painter KB, Haff GG, Ramsey MW, McBride J, Triplett T, Sands WA, Lamont HS, Stone ME, and Stone MH. Strength gains: Block versus daily undulating periodization weight training among track and field athletes. *International Journal of Sports Physiology and Performance* 7: 161-169, 2012.
120. Patton MQ. *Qualitative Research & Evaluation Methods*. Thousand Oaks, CA, USA: SAGE Publications, 2005.
121. Peterson MD, Rhea MR, and Alvar BA. Maximizing strength development in athletes: a meta-analysis to determine the dose-response relationship. *Journal of Strength & Conditioning Research* 18: 377-382, 2004.
122. Plisk SS and Stone MH. Periodization strategies. *Strength & Conditioning Journal* 25: 19-37, 2003.
123. Pritchard H, Barnes M, Keogh J, and McGuigan M. The effectiveness of Prilepins chart for strength improvements in recreationally strength trained males. *Journal of Strength & Conditioning Research* 30: S101, 2016.
124. Pritchard H, Keogh J, Barnes M, and McGuigan M. Effects and mechanisms of tapering in maximizing muscular strength. *Strength & Conditioning Journal* 37: 72-83, 2015.
125. Pritchard HJ, Barnes MJ, Stewart RJ, Keogh JW, and McGuigan MR. Short term training cessation as a method of tapering to improve maximal strength. *Journal of Strength & Conditioning Research* [Epub ahead of print], 2017.
126. Pritchard HJ, Tod DA, Barnes MJ, Keogh JW, and McGuigan MR. Tapering practices of New Zealand's elite raw powerlifters. *Journal of Strength & Conditioning Research* 30: 1796-1804, 2016.
127. Pyne DB, Mujika I, and Reilly T. Peaking for optimal performance: Research limitations and future directions. *Journal of Sports Sciences* 27: 195-202, 2009.

128. Raastad T, Bjørro T, and Hallen J. Hormonal responses to high-and moderate-intensity strength exercise. *European Journal of Applied Physiology* 82: 121-128, 2000.
129. Ratamess NA, Kraemer WJ, Volek JS, Maresh CM, VanHeest JL, Sharman MJ, Rubin MR, French DN, Vescovi JD, and Silvestre R. Androgen receptor content following heavy resistance exercise in men. *The Journal of Steroid Biochemistry and Molecular Biology* 93: 35-42, 2005.
130. Rhea MR and Alderman BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Research Quarterly for Exercise and Sport* 75: 413-422, 2004.
131. Rhea MR, Alvar BA, Ball SD, and Burkett LN. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *Journal of Strength & Conditioning Research* 16: 525-529, 2002.
132. Rhea MR, Alvar BA, and Burkett LN. Single versus multiple sets for strength: a meta-analysis to address the controversy. *Research Quarterly for Exercise and Sport* 73: 485-488, 2002.
133. Rhea MR, Alvar BA, Burkett LN, and Ball SD. A meta-analysis to determine the dose response for strength development. *Medicine & Science in Sports & Exercise* 35: 456-464, 2003.
134. Riad-Fahmy D, Read G, and Walker R. Salivary steroid assays for assessing variation in endocrine activity. *Journal of Steroid Biochemistry* 19: 265-272, 1983.
135. Rowbottom DG, Keast D, and Morton AR. The emerging role of glutamine as an indicator of exercise stress and overtraining. *Sports Medicine* 21: 80-97, 1996.
136. Rushall BS. A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sport Psychology* 2: 51-66, 1990.
137. Schinke RJ, Bonhomme J, McGannon KR, and Cummings J. The internal adaptation processes of professional boxers during the Showtime Super Six Boxing Classic: A qualitative thematic analysis. *Psychology of Sport and Exercise* 13: 830-839, 2012.
138. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength & Conditioning Research* 24: 2857-2872, 2010.
139. Schoenfeld BJ. Postexercise hypertrophic adaptations: A reexamination of the hormone hypothesis and its applicability to resistance training program design. *Journal of Strength & Conditioning Research* 27: 1720-1730, 2013.
140. Schoenfeld BJ, Ogborn D, and Krieger JW. Effects of resistance training frequency on measures of muscle hypertrophy: A systematic review and meta-analysis. *Sports Medicine*: 1-9, 2016.
141. Schoenfeld BJ, Pope ZK, Benik FM, Hester GM, Sellers J, Nooner JL, Schnaiter JA, Bond-Williams KE, Carter AS, Ross CL, Just B, Henselmans M, and Krieger J. Longer inter-set rest periods enhance muscle strength and hypertrophy in resistance-trained men. *Journal of Strength and Conditioning Research* 30: 1805-1812, 2016.
142. Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, and Tiryaki-Sonmez G. Influence of resistance training frequency on muscular adaptations in well-trained men. *Journal of Strength & Conditioning Research* 29: 1821-1829, 2015.
143. Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, Tiryaki-Sonmez G, and Alvar BA. Effects of different volume-equated resistance training loading

- strategies on muscular adaptations in well-trained men. *Journal of Strength & Conditioning Research* 28: 2909-2918, 2014.
144. Schwab R, Johnson GO, Housh TJ, Kinder JE, and Weir JP. Acute effects of different intensities of weight lifting on serum testosterone. *Medicine & Science in Sports & Exercise* 25: 1381-1385, 1993.
  145. Serfass RC, Stull GA, Alexander JF, and Ewing Jr JL. The effects of rapid weight loss and attempted rehydration on strength and endurance of the handgripping muscles in college wrestlers. *Research Quarterly for Exercise and Sport* 55: 46-52, 1984.
  146. Seynnes OR, de Boer M, and Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *Journal of Applied Physiology* 102: 368-373, 2007.
  147. Slater G, Rice AJ, Tanner R, Sharpe K, Gore CJ, Jenkins DG, and Hahn AG. Acute weight loss followed by an aggressive nutritional recovery strategy has little impact on on-water rowing performance. *British Journal of Sports Medicine* 40: 55-59, 2006.
  148. Slater GJ, Rice AJ, Sharpe K, Tanner R, Jenkins D, Gore CJ, and Hahn AG. Impact of acute weight loss and/or thermal stress on rowing ergometer performance. *Medicine & Science in Sports & Exercise* 37: 1387-1394, 2005.
  149. Smith DJ and Norris SR. Changes in glutamine and glutamate concentrations for tracking training tolerance. *Medicine & Science in Sports & Exercise* 32: 684-689, 2000.
  150. Spiering BA, Kraemer WJ, Vingren JL, Ratamess NA, Anderson JM, Armstrong LE, Nindl BC, Volek JS, Häkkinen K, and Maresh CM. Elevated endogenous testosterone concentrations potentiate muscle androgen receptor responses to resistance exercise. *The Journal of Steroid Biochemistry and Molecular Biology* 114: 195-199, 2009.
  151. Starkey DB, Pollock ML, Ishida Y, Welsch MA, Brechue WF, Graves JE, and Feigenbaum MS. Effect of resistance training volume on strength and muscle thickness. *Medicine & Science in Sports & Exercise* 28: 10, 1996.
  152. Stone MH, O'Bryant H, Garhammer J, McMillan J, and Rozenek R. A theoretical model of strength training. *Strength & Conditioning Journal* 4: 36-39, 1982.
  153. Stone MH, Potteiger JA, Pierce KC, Proulx CM, O'bryant HS, Johnson RL, and Stone ME. Comparison of the effects of three different weight-training programs on the one repetition maximum squat. *Journal of Strength & Conditioning Research* 14: 332-337, 2000.
  154. Storen O, Helgerud J, Stoa EM, and Hoff J. Maximal strength training improves running economy in distance runners. *Medicine & Science in Sports & Exercise* 40: 1087, 2008.
  155. Storey A and Smith HK. Unique aspects of competitive weightlifting: Performance, training and physiology. *Sports Medicine* 42: 769-790, 2012.
  156. Storey AG, Birch NP, Fan V, and Smith HK. Stress responses to short-term intensified and reduced training in competitive weightlifters. *Scandinavian Journal of Medicine & Science in Sports* 26: 29-40, 2015.
  157. Sturges JE and Hanrahan KJ. Comparing telephone and face-to-face qualitative interviewing: A research note. *Qualitative Research* 4: 107-118, 2004.
  158. Swinton PA, Lloyd R, Agouris I, and Stewart A. Contemporary training practices in elite British powerlifters: survey results from an international competition. *Journal of Strength & Conditioning Research* 23: 380-384, 2009.

159. Tan B. Manipulating resistance training program variables to optimize maximum strength in men: a review. *Journal of Strength & Conditioning Research* 13: 289-304, 1999.
160. Tanner R and Gore C. *Physiological Tests for Elite Athletes*. Human Kinetics, 2013.
161. Tavares LD, de Souza EO, Ugrinowitsch C, Laurentino GC, Roschel H, Aihara AY, Cardoso FN, and Tricoli V. Effects of different strength training frequencies during reduced training period on strength and muscle cross-sectional area. *European Journal of Sport Science*: 1-8, 2017.
162. Terzis G, Stratakos G, Manta P, and Georgiadis G. Throwing performance after resistance training and detraining. *Journal of Strength & Conditioning Research* 22: 1198-1204, 2008.
163. Thomas L and Busso T. A theoretical study of taper characteristics to optimize performance. *Medicine & Science in Sports & Exercise* 37: 1615-1621, 2005.
164. Tod DA, Bond KA, and Lavallee D. Professional development themes in strength and conditioning coaches. *Journal of Strength & Conditioning Research* 26: 851-860, 2012.
165. Tremblay MS, Copeland JL, and Van Helder W. Effect of training status and exercise mode on endogenous steroid hormones in men. *Journal of Applied Physiology* 96: 531-539, 2004.
166. Tuchscherer M. *The Reactive Training Manual: Developing your own custom training program for powerlifting*. Reactive Training Systems, 2008.
167. Turner A. The science and practice of periodization: A brief review. *Strength & Conditioning Journal* 33: 34-46, 2011.
168. Turner A, Brazier J, Bishop C, Chavda S, Cree J, and Read P. Data analysis for strength and conditioning coaches: using Excel to analyze reliability, differences, and relationships. *Strength & Conditioning Journal* 37: 76-83, 2015.
169. Twist C and Highton J. Monitoring fatigue and recovery in rugby league players. *International Journal of Sports Physiology and Performance* 8: 467-474, 2013.
170. Twist C, Waldron M, Highton J, Burt D, and Daniels M. Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *Journal of Sports Sciences* 30: 359-367, 2012.
171. Wade SM, Pope ZC, and Simonson SR. How prepared are college freshmen athletes for the rigors of college strength and conditioning? A survey of college strength and conditioning coaches. *Journal of Strength & Conditioning Research* 28: 2746-2753, 2014.
172. Weiss LW. The obtuse nature of muscular strength: The contribution of rest to its development and expression. *Journal of Strength & Conditioning Research* 5: 219-227, 1991.
173. Weiss LW, Coney HD, and Clark FC. Optimal post-training abstinence for maximal strength expression. *Research in Sports Medicine* 11: 145-155, 2003.
174. Weiss LW, Wood LE, Fry AC, Kreider RB, Relyea GE, Bullen DB, and Grindstaff PD. Strength/power augmentation subsequent to short-term training abstinence. *Journal of Strength & Conditioning Research* 18: 765-770, 2004.
175. West DW and Phillips SM. Anabolic processes in human skeletal muscle: restoring the identities of growth hormone and testosterone. *The Physician and Sportsmedicine* 38: 97-104, 2010.

176. West DW and Phillips SM. Associations of exercise-induced hormone profiles and gains in strength and hypertrophy in a large cohort after weight training. *European Journal of Applied Physiology* 112: 2693-2702, 2012.
177. Williams TD, Toluoso DV, Fedewa MV, and Esco MR. Comparison of periodized and non-periodized resistance training on maximal strength: A meta-analysis. *Sports Medicine*: 1-18, 2017.
178. Willoughby DS. The effects of mesocycle-length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *Journal of Strength & Conditioning Research* 7: 2-8, 1993.
179. Wilson JM and Wilson GJ. A practical approach to the taper. *Strength & Conditioning Journal* 30: 10-17, 2008.
180. Winwood PW, Hume PA, Cronin JB, and Keogh JW. Retrospective injury epidemiology of strongman athletes. *Journal of Strength & Conditioning Research* 28: 28-42, 2014.
181. Winwood PW, Keogh JW, and Harris NK. The strength and conditioning practices of strongman competitors. *Journal of Strength & Conditioning Research* 25: 3118-3128, 2011.
182. Winwood PW, Keogh JW, and Harris NK. Interrelationships between strength, anthropometrics, and strongman performance in novice strongman athletes. *The Journal of Strength & Conditioning Research* 26: 513-522, 2012.
183. Wolfe BL, Lemura LM, and Cole PJ. Quantitative analysis of single-vs. multiple-set programs in resistance training. *Journal of Strength & Conditioning Research* 18: 35-47, 2004.
184. Zaras N, Stasinaki A, Krase A, Methenitis S, Karampatsos G, Georgiadis G, Spengos K, and Terzis G. Effects of tapering with light vs. heavy loads on track and field throwing performance. *Journal of Strength & Conditioning Research* 28: 3484-3495, 2014.
185. Zourdos MC, Jo E, Khamoui AV, Lee S-R, Park B-S, Ormsbee MJ, Panton LB, Contreras RJ, and Kim J-S. Modified daily undulating periodization model produces greater performance than a traditional configuration in powerlifters. *Journal of Strength & Conditioning Research* 30: 784-791, 2016.

## APPENDICES

### Appendix A: Abstracts of Thesis Chapters

#### Chapter Three Abstract – Strength & Conditioning Journal

Pritchard H, Keogh J, Barnes M, and McGuigan M. Effects and mechanisms of tapering in maximizing muscular strength. *Strength & Conditioning Journal* 37(2): 72-83, 2015.

#### Abstract

Tapering for maximal strength requires reductions in training load to recover from the fatigue of training. It is performed prior to important competitions to allow optimal performance at specific events. Reductions in training volume, with maintained or small increases in training intensity, appear most effective for improving muscular strength. Training cessation may also play a role, with less than one week being optimal for performance maintenance, and two to four days appearing to be optimal for enhanced maximal muscular strength. Improved performance may be related to more complete muscle recovery, greater neural activation and an enhanced anabolic environment.

## Chapter Four Abstract – Journal of Strength & Conditioning Research

Pritchard H, Tod D, Barnes M, Keogh J, and McGuigan M. Tapering practices of New Zealand's elite raw powerlifters. *Journal of Strength & Conditioning Research* 30(7): 1796-1804, 2016.

### Abstract

The major aim of this study was to determine tapering strategies of elite powerlifters. Eleven New Zealand powerlifters ( $28.4 \pm 7.0$  years, best Wilks score of  $431.9 \pm 43.9$  points) classified as elite were interviewed, using semi-structured interviews, about their tapering strategies. Interviews were transcribed verbatim and content analyzed. Total training volume peaked  $5.2 \pm 1.7$  weeks from competition while average training intensity (of 1RM) peaked  $1.9 \pm 0.8$  weeks from competition. During tapering volume was reduced by  $58.9 \pm 8.4\%$  while intensity was maintained (or slightly reduced) and the final weight training session was performed  $3.7 \pm 1.6$  days out from competition. Participants generally stated that tapering was performed to achieve full recovery; that accessory work was removed around two weeks out from competition; and, deadlifting takes longer to recover from than other lifts. Typically participants stated that trial and error, and changes based on 'feel' were the sources of tapering strategies; equipment used and movements performed during tapering are the same as in competition; nutrition was manipulated during the taper (for weight cutting and/or performance aims); and, poor tapering occurred when too long (one week or more) was taken off training. These results suggest that athletes may benefit from continuing to strength train prior to important events with reduced volume and maintained intensity. Only exercises that directly assist sports performance should remain in the strength program during tapering, to assist with reductions in fatigue while maintaining/improving strength expression and performance.

## Chapter Five Abstract – Journal of Strength & Conditioning Research

Pritchard H, Barnes M, Stewart R, Keogh J, and McGuigan M. Short term training cessation as a method of tapering to improve maximal strength.

*Journal of Strength & Conditioning Research* DOI: 10.1519/

JSC.0000000000001803.

### Abstract

The aim of this study was to determine the effects of two different durations of training cessation on upper and lower body maximal strength performance, and to investigate the mechanisms underlying performance changes following short term training cessation. Eight resistance trained males ( $23.8 \pm 5.4$  years,  $79.6 \pm 10.2$  kg,  $1.80 \pm 0.06$  m, relative deadlift 1RM of  $1.90 \pm 0.30$  times bodyweight) each completed two four-week strength training periods followed by either 3.5 days ( $3.68 \pm 0.12$  days) or 5.5 days ( $5.71 \pm 0.13$  days) of training cessation. Testing occurred pre-training (T1), on the final day of training (T2) and following each respective period of training cessation (T3). Participants were tested for salivary testosterone and cortisol, plasma creatine kinase, psychological profiles, and performance tests (countermovement jump (CMJ), isometric mid-thigh pull (MTP) and isometric bench press (IBP)) on a force plate. Participants' bodyweight increased significantly over time ( $P = 0.022$ ). CMJ height and IBP relative peak force showed significant increases over time ( $P = 0.013$  and  $0.004$ , respectively). Post-hoc testing showing a significant increase between T1 and T3 for both CMJ height and IBP relative peak force ( $P = 0.022$  and  $0.011$ , respectively, both with effect sizes (ES) of  $0.30$ ). No other significant differences were seen for any other measures. These results suggest that a short period of strength training cessation can have positive effects on maximal strength expression, perhaps due to decreases in neuromuscular fatigue.

## Chapter Six Abstract – To be Submitted for Publication

### Abstract

This randomised crossover design study investigated the effects of different training intensities during a strength training taper with equal training volume reductions. Eleven strength-trained males (age =  $21.3 \pm 3.3$  years, BW =  $92.3 \pm 17.6$  kg, height =  $1.82 \pm 0.08$  m, relative 1RM deadlift  $1.90 \pm 0.20$  times BW) completed two four-week strength training blocks, followed by a taper week with reduced volume (~70%) and either increased (Taper A, 5.9%) or decreased (Taper B, -8.5%) intensity. Testing occurred pre-training (T1), following four weeks of training (T2), and following each taper week (T3). Testing involved measuring salivary testosterone and cortisol, plasma creatine kinase (CK), a daily analysis of life demands in athletes (DALDA) questionnaire, countermovement jump (CMJ), isometric mid-thigh pull (MTP) and isometric bench press (IBP). CMJ height showed significant improvements over time ( $P < 0.001$ ), with significant increases from T1 to T2 ( $P = 0.010$ ; pooled ES = 0.23), T1 to T3 ( $P = 0.001$ ; pooled ES = 0.37) and T2 to T3 ( $P = 0.002$ ; pooled ES = 0.14). CMJ flight time: contraction time showed significant improvements over time ( $P = 0.004$ ), with significant increases from T1 to T2 ( $P = 0.012$ ; pooled ES = 0.27). MTP relative peak force showed significant improvements over time ( $P = 0.033$ ), with significant increases from T1 to T2 ( $P = 0.013$ ; pooled ES = 0.25). No other significant differences were found for time, taper or taper by time. However, the higher intensity taper tended to produce more favourable ES improvements. These results suggest a taper with volume reductions has positive effects on maximal strength and power performance, with a tendency for a taper involving 5% greater training intensities producing more favourable changes than a taper with 10% reduced training intensities compared to the previous training phase.

## Appendix B: Abstracts of Poster Presentations

### 2016 NSCA Conference Poster Abstract

This appendix consists of the abstract of the following poster presented at the NSCA 2016 National Conference in New Orleans:

Pritchard, H., Barnes M., Keogh, J., & McGuigan, M. The effectiveness of Prilepin's chart for strength improvements in recreationally strength trained males. *Journal of Strength & Conditioning Research* 30(S2): S101, 2016.

Prilepin's chart (or Prilepin's table) was developed, based upon observations of elite weightlifters training methods, to act as a guide in the selection of optimal set, rep and intensity schemes when training to improve performance in weightlifting. It has also been used, anecdotally, to successfully guide resistance training in powerlifting and other sports. However, there is currently no research investigating the effectiveness of its guidelines for strength improvements specific to the three powerlifts.

**Purpose:** To determine the effectiveness of using Prilepin's chart to guide strength training for improving powerlifting performance over a four week period in resistance trained males.

**Methods:** Nine resistance trained males (mean  $\pm$  SD; age =  $24.7 \pm 4.9$  years, BW  $82.7 \pm 8.8$  kg) participated in this investigation. The participants were tested for one repetition maximum (1RM) in the powerlifts, as well as for their 2-10RM to estimate 1RM's on accessory movements (or variations on the powerlifts), before and after the four weeks of training. Pre-testing took place a minimum of three and no more than seven days prior to the commencement of the training period, and post testing occurred a minimum of four and no more than seven days following the final training session. The training programme was based on Prilepin's chart (Table B.1). Statistical analysis involved using two tailed, paired, T-tests with a significance level set at  $P < 0.05$ . ES was calculated by dividing the change in 1RM by the initial SD.

**Table B.1:** Prilepin's table

Prilepin's Table			
%	Reps/Set	Range	Optimal
<70	3-6	18-30	24
70-79	3-6	12-24	18
80-89	2-4	10-20	15
90+	1-2	4-10	7

**Results:** Significant absolute strength improvements occurred for all powerlifts; squat from  $122.2 \pm 26.6$  kg to  $134.2 \pm 25.5$  kg ( $P < 0.001$ , ES 0.45), bench press from  $94.7 \pm 22.3$  kg to  $100.6 \pm 22.7$  kg ( $P = 0.006$ , ES 0.26), and deadlift from  $158.9 \pm 34.1$  kg to  $172.2 \pm 36.4$  kg ( $P < 0.001$ , ES 0.39). Significant strength improvements also occurred for all powerlifts relative to BW; squat from  $1.47 \pm 0.22$  x BW to  $1.60 \pm 0.21$  x BW ( $P < 0.001$ , ES 0.61); bench press from  $1.14 \pm 0.19$  x BW to  $1.20 \pm 0.19$  x BW ( $P = 0.028$ , ES 0.33), and deadlift from  $1.91 \pm 0.28$  x BW to  $2.05 \pm 0.30$  x BW ( $P = 0.002$ , ES 0.50).

**Conclusions:** With only four weeks of powerlifting specific strength training, based on the guidelines provided by Prilepin's chart, strength gains can be made in the three powerlifts in resistance trained males. Improvements tended to be greater for the lower body dominant powerlifts of the squat and deadlift.

**Practical Applications:** Prilepin's chart can be used as a strength training tool in sports where increasing strength in the muscle groups and movements associated with the powerlifts is important. This research confirms the anecdotally reported success of this training methodology in improving strength in the three powerlifts.

## 2016 ASCA Conference Poster Abstract

This appendix consists of the abstract of the following poster presented at the 2016 Australian Strength & Conditioning Association (ASCA) International Conference on Applied Strength and Conditioning in Melbourne:

Pritchard, H., Barnes, M., Keogh, J., & McGuigan, M. Relationships between 1RM powerlifting competition lifts and common modified and accessory exercises used in training – a pilot study. *Journal of Australian Strength and Conditioning* 24(6): 48-49, 2016.

**Introduction:** Powerlifting involves an athlete aiming to achieve the highest total across three attempts per lift on the Squat, Bench Press and Deadlift. Specificity is one of the most important training principles and it is easily applied in the sport of Powerlifting whereby an athlete can simply perform the competition lifts regularly in training. However, to address lift-specific weaknesses athletes often perform modified (or variation) exercises. Modified exercises are similar to competition movements but have been altered to target weaknesses, such as performing a Bench Press with an extended pause on the chest to address a weakness when pressing from bottom position. The aim of this investigation was to investigate the relationships between strength in these exercises and competition movements, as well as between the competition movements themselves.

**Methods:** Thirteen resistance trained (2+ years) men were tested for their 1RM in the competition movements and 2-8RM of five modified and three accessory movements (see Table B.2). Participants weighed  $83.8 \pm 13.6$  kg, were aged  $24.9 \pm 6.3$  years and had relative 1RM's of: Squat  $1.51 \pm 0.26$  x BW, Bench Press  $1.11 \pm 0.22$  x BW, and Deadlift  $1.98 \pm 0.33$  x BW. Competition movements were then compared to each other, and to the other exercises, to determine the relative percentages and an  $R^2$  value (for a linear regression) was calculated using Microsoft Excel.

## Results:

**Table B.2:** Relationships of powerlift 1RM's to modified & alternative exercises 1RM's

Relationship of Squat 1RM		
	% of Squat	R <sup>2</sup>
Bench Press	74.0 ± 10.6 %	0.6824
Front Squat	73.2 ± 6.4 %	0.8366
Good Morning	55.8 ± 9.5 %	0.7483
Relationship of Bench Press 1RM		
	% of Bench Press	R <sup>2</sup>
2ct Bench Press	87.7 ± 3.8 %	0.9782
Barbell Row	87.9 ± 11.8 %	0.7443
CG Bench Press	94.3 ± 2.6 %	0.9871
Military Press	61.0 ± 6.8 %	0.8386
Relationship of Deadlift 1RM		
	% of Deadlift	R <sup>2</sup>
2" Deficit Deadlift	88.4 ± 5.2 %	0.9360
Barbell Row	48.9 ± 5.7 %	0.8538
Bench Press	56.3 ± 9.2 %	0.6520
Good Morning	42.6 ± 8.4 %	0.7066
Squat	76.3 ± 8.4 %	0.7550

*N.B. Percentages represented as means ± SD; 2ct Bench Press = pausing for approx. 2 seconds on the chest; CG = close grip.*

**Discussion:** The strongest relationships were found with the exercises that most closely resembled the main movements, e.g. Close Grip Bench Press to regular Bench Press. The Barbell Row was more accurately predicted by the Deadlift than the Bench Press, and the Good morning by the Squat than the Deadlift. Such information can act as a guide in selecting weights in training these movements when they may not have been previously performed. However, caution should be applied due to some standard deviations. Future investigations should investigate relationships with stronger and weaker participants, and more participants be recruited.

**Practical Applications:** Athletes and strength and conditioning practitioners can use the results of this investigation as a guide to weight selection when performing modified exercises in training.

## Appendix C: Isometric Bench Press Reliability Technical Note

The IBP set up utilised in Chapter Five and Chapter Six was novel. However, the test was shown to be reliable for several variables and had some interesting correlations. Data from 20 participants (age =  $23.6 \pm 5.3$  years, BW =  $89.5 \pm 16.1$  kg, and, 1RM bench press =  $98.6 \pm 22.3$  kg) were analysed and CV's were calculated using the data from three maximal IBP's performed in one session, using commercial computer software (Excel, Microsoft Corporation, WA, USA). The CV results are shown in Table C.1 below.

**Table C.1:** Isometric bench press CV results

Isometric Bench Press Measure	Coefficient of Variation (%)
IBP Relative Peak Force (N/kg)	3.4%
IBP Average Force (N)	5.2%
IBP mRFD (N/s)	15.5%

The above results show that IBP relative peak force produced the most reliable results. The value of 3.4% for relative peak force is similar to the CV values reported for MTP peak force in Chapter Five (3.2%) and Chapter Six (3.3%). This result indicates the IBP relative peak force measurement utilised within this thesis shows similar within-subject reliability to MTP peak force, a test which has shown reliability in the literature previously (106). Furthermore, Turner et al. (168) recommended a CV of <5% be utilised for fitness tests; IBP relative peak force is within this guideline and IBP average force approaches it. Therefore, the present method of IBP force testing was reliable.

Pearson correlations were calculated using a bench press 1RM and the best IBP (highest peak force) from the trials above, performed within one week of each other. These were calculated using commercial computer software (Sigma Plot 11.0, Systat Software, Inc., Chicago, Illinois, USA).

- A very strong positive correlation ( $r = 0.76$ ) was found between bench press 1RM and IBP peak force ( $P < 0.01$ ).
- A strong positive correlation ( $r = 0.57$ ) was found between relative bench press 1RM and IBP relative peak force ( $P < 0.01$ ).

These correlations are similar to the findings of McGuigan and Winchester (105) who found strong to very strong correlations ( $r = 0.61 - 0.72$ ) between MTP peak force and several 1RM tests (back squat, bench press and power clean).

## Appendix D: Powerlifting Competition Reliability Technical Note

The results of IPF Classic World Championships held in 2014, 2015 and 2016 were analysed using the Goodlift database (publicly available online: <http://goodlift.info>). Male athletes that competed at the 2016 World Championships, and at least one other within the time frame were included in the analysis. Athletes who did not achieve a total, or were injured were excluded.

Forty-two athletes were included in the analysis (age =  $30.9 \pm 5.3$  years, BW =  $100.4 \pm 38.7$  kg), nineteen of these athletes had competed at all three World Championships. Fourteen of the 42 athletes were podium finishers (age =  $34.0 \pm 4.9$  years, BW =  $103.5 \pm 45.8$  kg), and their results were also analysed independently. Log-transformed CV's and 95% confidence intervals (CI) were calculated using previously described methods (104). Results are presented in Table D.1

**Table D.1:** Reliability of powerlifting performance

Event	All Athletes		Podium Athletes	
	CV (%)	95% CI	CV (%)	95% CI
Squat	3.0	2.5-3.6	2.0	1.5-3.2
Bench Press	2.5	2.1-3.2	2.2	1.6-3.4
Deadlift	3.0	2.5-3.8	2.3	1.7-3.7
Total	2.0	1.6-2.5	1.2	0.9-1.9

The CV's above display the reliability of performance in elite male powerlifters. The bench press displayed the greatest reliability of the three competition lifts, however the 95% CI showed considerable overlap across all lifts. The three-lift total had lower CV's than all individual lifts, indicating that changes amongst lifts must often occur which result in the three-lift total displaying less variation (e.g. a small improvement could occur in the squat and deadlift with a greater decrement in bench press performance, resulting in a similar three-lift total). Interestingly, the podium level competitors showed greater reliability in comparison to all athletes. These results are similar to those found amongst elite Olympic weightlifters (104), with CV's for the clean and jerk of 2.3%, and the snatch 2.7%. As with the podium finishers in the present investigation, the performance amongst higher level competitors (top five) was also more reliable in comparison to the lower placed Olympic weightlifters.

Results from the 2016 championship were also analysed to determine the percentage differences in competition placings. The results are shown in Table D.2.

**Table D.2:** Percentage differences for total result based on placings

Placing	First	Second	Third
First			
Second	3.6 ± 3.7%		
Third	5.6 ± 4.3%	2.1 ± 1.9%	
Fourth	7.8 ± 4.5%	4.3 ± 2.6%	2.3 ± 1.4%

*N.B. Displayed as mean ± SD.*

These results demonstrate the importance of small performance improvements to an athletes' chance of success in the sport of powerlifting. For example, the difference between an athlete finishing in fourth-place compared to a podium finish involves an average difference of only 2.3% to their total. Clearly, very minor changes in performance can be significant to athletes' placings at an event. Changes of a similar magnitude have previously been demonstrated through tapering, with competition performance improvements following tapering averaging around 3% (97). Interesting, in swimming the difference between a gold medal and fourth place was only 1.62% (114), an even smaller change. Although the percentage differences in times and weight lifted cannot be directly compared, this displays the importance of small performance improvements in sports with vastly difference physiological requirements.

This investigation has demonstrated that the performances of elite strength athletes show little variation over several years and that small performance changes can result in significant improvements to athletes' results at competitions. Therefore, if an athlete can implement effective tapering strategies to enhance performance prior to competitions they could considerably improve their placings in competition.

## Appendix E: Additional Research Outputs since Beginning the Doctor of Philosophy

### Publications:

- Perry, B., **Pritchard, H.**, & Barnes, M. (2016). Cardiovascular and strength responses to acute ammonia inhalation. *European Journal of Applied Physiology*, 116(3), 583-92.
- **Pritchard, H.**, & Morton, H. (2015). Powerlifting success and failure at the 2012 Oceania and 2013 Classic World Championships. *Journal of Australian Strength and Conditioning*, 23(6), 67-70.
- **Pritchard, H.**, Fink, P., & Stannard, S. (2015). The effects of concentric/eccentric training versus concentric only training on peak power and functional muscle performance. *Journal of Australian Strength and Conditioning*, 23(6), 71-75.
- Cochrane, D., Coley, K., **Pritchard, H.**, & Barnes, M. (2015). Vibration exercise as a warm-up modality for deadlift power output. *The Journal of Strength and Conditioning Research*, 29(4), 1033-1039.
- **Pritchard, H.**, Stannard, S., & Barnes, M. (2014). Ammonia inhalant & stimulant use among powerlifters: Results from an international survey. *Journal of Australian Strength and Conditioning*, 22(5), 52-54.

### Conference Poster Presentations:

- Wilson, A., **Pritchard, H.**, Stewart, R., & Tildesley, J. The effects of caffeine on maximal strength and power in recreationally trained females. (November 2016). *Poster presented at the 2016 Australian Strength and Conditioning Association's International Conference on Applied Strength and Conditioning, Melbourne, Australia.*
- **Pritchard, H.**, Fink, P., & Stannard, S. The effects of concentric/eccentric training versus concentric only training on peak power and functional muscle performance. (November 2015). *Poster presented at the 2015 Australian Strength and Conditioning Association's International Conference on Applied Strength and Conditioning, Gold Coast, Australia.*

- **Pritchard, H., & Morton, H.** Powerlifting success and failure at the 2012 Oceania and 2013 Classic World Championships. (November 2015). *Poster presented at the 2015 Australian Strength and Conditioning Association's International Conference on Applied Strength and Conditioning, Gold Coast, Australia.*
- **Pritchard, H., Stannard, S., & Barnes, M.** (November 2014). Ammonia inhalant & stimulant use among powerlifters: Results from an international survey. *Poster presented at the 2014 Australian Strength and Conditioning Association's International Conference on Applied Strength and Conditioning, Melbourne, Australia.*

## Appendix F: Ethical Approval

### Ethical Approval for Chapter Four

 <p><b>AUT</b> UNIVERSITY TE WĀHANGA ARANGI O TAMAU KĀKĀRIKI</p>	<p><b>AUT EC</b> <b>SECRETARIAT</b></p>
<p>11 August 2014</p>	
<p>Mike McGuigan Faculty of Health and Environmental Sciences</p>	
<p>Dear Mike</p>	
<p>Re Ethics Application:       <b>14/218 Tapering practices of New Zealand's elite raw powerlifters.</b></p>	
<p>Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).</p>	
<p>Your ethics application has been approved for three years until 11 August 2017.</p>	
<p>As part of the ethics approval process, you are required to submit the following to AUTEC:</p>	
<ul style="list-style-type: none"><li>• A brief annual progress report using form EA2, which is available online through <a href="http://www.aut.ac.nz/researchethics">http://www.aut.ac.nz/researchethics</a>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 11 August 2017;</li><li>• A brief report on the status of the project using form EA3, which is available online through <a href="http://www.aut.ac.nz/researchethics">http://www.aut.ac.nz/researchethics</a>. This report is to be submitted either when the approval expires on 11 August 2017 or on completion of the project.</li></ul>	
<p>It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.</p>	
<p>AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.</p>	
<p>To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at <a href="mailto:ethics@aut.ac.nz">ethics@aut.ac.nz</a>.</p>	
<p>All the very best with your research,</p>	
	
<p>Kate O'Connor Executive Secretary Auckland University of Technology Ethics Committee</p>	
<p>Cc:       Harden Pritchard <a href="mailto:h.pritchard@uol.ac.nz">h.pritchard@uol.ac.nz</a></p>	
<p><b>A u c k l a n d   U n i v e r s i t y   o f   T e c h n o l o g y   E t h i c s   C o m m i t t e e</b> WA606F Level 6 WA Building City Campus Private Bag 92008 Auckland 1142   Ph: +64-9-821-8888 ext 8318 email <a href="mailto:ethics@aut.ac.nz">ethics@aut.ac.nz</a></p>	

Ethical Approval for Chapter Five and Chapter Six



AUTEC  
SECRETARIAT

18 May 2015

Mike McGuigan  
Faculty of Health and Environmental Sciences

Dear Mike

Re Ethics Application: **15/138 Tapering strategies to enhance maximal strength in men**

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

Your ethics application has been approved for three years until 18 May 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 18 May 2018;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 18 May 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz).

All the very best with your research,

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

Cc: Hayden Pritchard [h\\_pritchard@uol.ac.nz](mailto:h_pritchard@uol.ac.nz)

A u c k l a n d   U n i v e r s i t y   o f   T e c h n o l o g y   E t h i c s   C o m m i t t e e

WA506F Level 5 WA Building City Campus

Private Bag 92008 Auckland 1142 Ph: +64-9-921-9999 ext 8318 email [ethloc@aut.ac.nz](mailto:ethloc@aut.ac.nz)